Ocean Engineering 250 (2022) 110196

Contents lists available at ScienceDirect

Ocean Engineering

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

Local tailored design of deep water composite risers subjected to burst, collapse and tension loads

Chiemela Victor Amaechi [a,b,*]

[a] Lancaster University, Department of Engineering, Bailrigg, Lancaster, LA1 4YR, UK
[b] Standards Organisation of Nigeria (SON), 52 Lome Crescent, Wuse Zone 7, Abuja, Nigeria

ARTICLE INFO

Keywords:
Composite riser pipe
Tailored local design
Composite marine risers
Finite element method (FEM)
Composite riser buckling
Numerical modelling

ABSTRACT

There is an increasing demand for more sustainable and adaptable technologies in the offshore industry. Thus, composite structures are more frequently used in the industry. Secondly, the shift in offshore exploration from shallow to deep waters has necessitated advancements on more lightweight composite structures to minimise platform loads, ease fluid transport, and service, using conduit pipes like composite production risers (CPR). The properties of composites are harnessed to improve riser weight and strength performance as Composite risers. In this research, the local tailored design of deep water composite risers was subjected to burst, collapse, tension and combined loads. Three design methodologies are considered-conventional, local, and tailored designs for different configurations. The structure is made up of configurations having 17 layers, 18 layers, 19 layers, 20 layers and 21 layers. The numerical technique for the CPR model with 3 m section considered five loadings. The model was developed utilising ANSYS ACP to conduct the numerical stress analysis with parametric studies. From the design, it is recommended to consider liners like PA12 and include environmental loads from global design. This study presents the CPR behaviour. Since CPR structures are response-sensitive and fatigue-sensitive, the global dynamic analysis of full-length composite riser is recommended.

1. Introduction

Currently, the quest for energy in the offshore industry has led to various advances in material development for both renewable energy and non-renewable energy. With the vast deposits of oil and gas and other deep water oil reserves, the industry requires newer technologies. As a result of the growing demand for more sustainable and adaptable materials, composite materials are being used more frequently in the industry (Amaechi, 2022; Amaechi et al., 2019a, 2019b, 2019c, 2019d, 2019e, 2019f). Furthermore, the recent trend in offshore exploration from shallow to deep waters has necessitated advancements such as more lightweight composite materials to minimise platform loads, ease fluid transport and service, and conduit pipes. These conduits include composite production risers (CPR) and marine bonded composite hoses (Amaechi et al., 2021a, 2021b; 2021c; 2021d; 2021e; 2021f). In principle, the properties of composites are harnessed to improve riser weight and strength performance as Composite risers (Ye et al., 2021; Akula, 2014; Alexander et al., 2013; Wang et al., 2011a, 2012a; Amaechi et al., 2019a, Amaechi and Ye, 2017). Generally, deep water explorations require longer risers, which result in significant increase in the weight. As shown on the deployed composite riser using m-pipe in Fig. 1, the deeper the water depths, the longer the riser required as such having composite risers would lead to weight reduction on platforms.

CPR application have been identified as a very novel approach to solve the problem, as composites improve the performance of the risers (Amaechi et al., 2019a, Amaechi and Ye, 2017; Wang et al., 2011b, 2012b). Light-weight, highly fatigue resistant, highly resistant to corrosive chemicals, and high stiffness-to-strength characteristic properties are only a few of the benefits of composite materials that could be used in a riser build. As a result of its low bending stiffness, the composite structure is lightweight. Studies on composite risers evolved from those on marine risers (Hanonge, et al. 2010; Bai and Bai, 2005; Sparks, 2018; Dareing, 2019, 2012; Pham et al., 2014, 2016), composite cylindrical tubes (Sparks et al., 1988, 1989, 1992; Drey et al., 1997; Salama et al., 1998; Baldwin et al., 2002), composite shells (Bakaiyan et al., 2009; Ye, 2003; Xia et al., 2001; Ye and Soldatos, 1995; Amaechi et al., 2021g). Basically, composite riser structures can be classified as self-contained structures, and are similar to marine risers like flexible bonded risers, Top Tensioned Risers (TTRs) and Steel Catenary Risers (SCRs). Hence, these risers depend on marine engineering supporting structures such as

* Corresponding author. Lancaster University, Department of Engineering, Bailrigg, Lancaster, LA1 4YR, UK.
E-mail addresses: c.amaechi@lancaster.ac.uk, chiemelavic@gmail.com.

https://doi.org/10.1016/j.oceaneng.2021.110196
Received 9 June 2021; Received in revised form 22 September 2021; Accepted 12 November 2021
Available online 21 March 2022

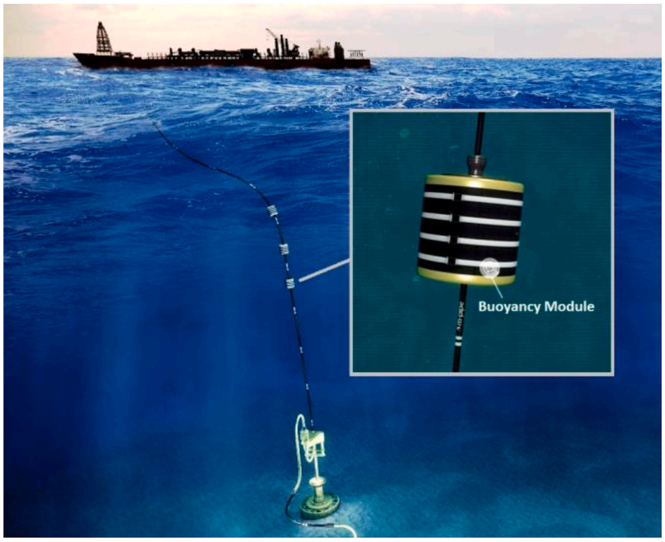

Fig. 1. Composite riser deployed showing FPSO, buoyancy module and Magma's m-pipe (Courtesy: MagmaGlobal 2016).

marine risers on deep-draft semisubmersible platforms (Zou et al., 2014, Zou, 2008; Odijie et al., 2017a, 2017b, Amaechi et al., 2021h, 2021i, 2021j, 2021k) and marine hoses on CALM buoy systems (Amaechi et al., 2021l, 2022b, 2022c, 2022e Amaechi and Ye, 2022). The performance of composite marine risers under water conditions is subject to environmental conditions, such as water waves, since they are dependent on other platforms (Sun et al., 2013, 2014a; Amaechi and Ye, 2017, 2019a, 2019b; Amaechi, 2022). These loads must be carefully considered in order to construct a composite riser using industry specifications (ABS, 2017; DNVGL, 2015, 2017a, 2017b, 2017c; DNV, 2002, 2010a, 2010b, 2013). A schematic depicting common loadings on a composite riser structure, as well as the layer stack-up and a transversion of the composite riser layers is shown in Fig. 2.

Developments of composite risers have been on-going for over four decades in different project designs (Baldwin et al., 1997, 1998, 2002; Pham et al., 2016; Sparks et al., 1992, 1988; Wang et al., 2015, 2011b; Amaechi et al., 2019a, 2019b, 2017). Earlier studies in literature (Tamarelle and Sparks, 1987; Salama et al., 1986, 1999; Johnson et al., 1999; Ochoa et al., 2005; Ochoa, 2006; Ward et al., 2007; Kim et al., 2005a, 2005b) stemmed from the design patents on composite tubes (Baldwin et al., 2000; Salama and Spencer, 2006; Ahlstone, 1973). Ahlstone (1973) patented a filament wound drilling riser having an inner lining made of glass fibres coated with epoxy resins, while Salama et al. (2006) patented the metal-lined composite risers for offshore applications. Another patent progress was achieved called the trap-lock end fitting for thermoset composite risers (Baldwin et al., 2000). Research institutions like the Institut Francais du Petrole (IFP), the National Institute of Standards and Technology (NIST)'s Advanced Technology Programs (ATP), and Aerospatiale of France all recorded significant developments on composite tubes later in the 1980s. It was recorded that the first application of composite riser on a platform was demonstrated in July 2001 on the Tension Leg Platform (TLP) at Heidrun field, by demonstrating the installation of the joint of a composite riser on three (3) positions of a typical drilling string, as it was the first time to try this on a large scale and real-life scenario, but it operated functionally for about 45 days (Amaechi et al., 2019a, 2022a, 2022d, Amaechi and Ye, 2021; Salama et al., 2002; Bybee, 2003; Melve et al., 2008; Pham et al., 2016). The Magnolia Project handled by Kvaerner Oilfield Products, Conoco Phillips with Chevron Texaco, in March 2003 after some structural integrity findings on the steel liner were reported due to pressure integrity. This project led to the need for composites as liners and recommended the optimal angle for the model is $\pm 55^{\circ}$. A notable improvement on the angled ply was the improvement on a composite riser by introducing an off-axis reinforcement at an angle of $\pm 55^{\circ}$, which was justified as weight saving and improving efficiency using netting theory (Picard et al., 2007). From the study, it was decided to apply the best ply angle of $\pm 54.7^{\circ}$ in the riser layers. Based on the modelling approach, homogenization of composite riser was one successful modelling approach that has been successful (Kim, 2007, Singh and Ahmad, 2014; Sun et al., 2014a, 2014b). Sun et al. (2014a) presented a homogenised model with stress analysis conducted on a multi-layered CPR using four loadings -torsion, bending, axial tension and axial pressure. The homogenised elastic constants of cylindrically orthotropic composite risers are calculated using force-deformation equivalence, with the stress and strain distributions in each layer

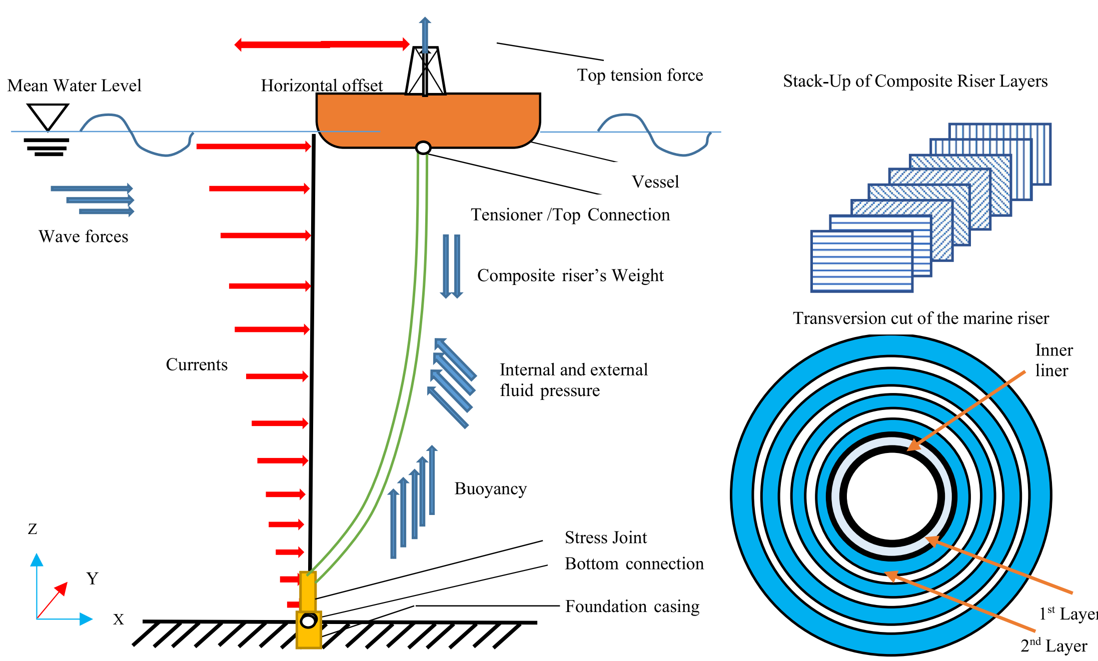

Fig. 2. Schematic on a composite marine riser showing loads, stack-up and transversion-cut of plies.

taken into consideration. According to the authors, stress assessments of composite cylinders with several layers of different fibre angles or materials can be carried out efficiently because there is no obligation to explicitly enforce interfacial continuity in homogenization method. By replacing complex models of riser sections with homogenised riser sections, homogenised elastic constants can substantially speed up the analysis of whole composite riser systems. Another important aspect of the composite production risers (CPR) is the application model based on global and local design (Fernandes da Silva et al., 2013, Tan et al., 2015, Akula, 2014, Hoen, 2003, Amaechi et al., 2019e, Wang et al., 2019, Singh and Ahmad, 2014). Singh et al. (2014) carried out a local and global analysis of composite production risers under random sea conditions by considering critical loads in the design using ABAQUS. Failure damage criteria was carried out to ensure the design is safe and the global analysis was carried out using the segmented length model, to obtain power spectral density (PSD) plot and root mean square (RMS) plot of the von-Mises stress. Hoen (2003) modelled a complaint composite riser to ascertain the global behaviour, while Sun et al. (2014b) investigated on the fatigue life prediction of CPR, which are based on global and local design. Amaechi et al. (2019a, 2022d) presented different numerical approaches for the local design of composite risers for deep waters by considering ANSYS ACP (ANSYS Composite Prep-Post) module to discuss the composite materials and their effects, such as AS4/PEEK, carbon fiber/epoxy (T700), glass fiber/epoxy (S-2), and the composite lamination on the factor of safety of composite risers and presented an optimum design method by analyzing the stress of different functional layers, and concluded that the optimum angle for the angled plies from Netting Theory was $\pm 53.5^{\circ}$. The mechanical analysis of a flexible riser with carbon fibre composite tension armour was proposed by Zhang et al. (2021), resulting in a hybrid composite-flexible riser. The progressive harm theory of composite materials was applied to the entire hybrid composite-flexible riser in the analysis, which was mechanically studied and compared to the original flexible riser. The weight of the riser was reduced by 9.73 kg/m, and the axial tensile stiffness was reduced by 17.10%, while the axial tensile strength improved by 130.0%, as it could meet the torsion and bending design strength requirements. This technique has also been applied to bonded composite marine hoses used in offshore loading and unloading operations (Zhou et al., 2018; Gao et al., 2018; Amaechi et al., 2022b). For certain composite riser configurations, Wang et al. (2011, 2013, 2015) used ANSYS APDL to design a global and local design of deep water composite risers and obtained results of stresses along the fibre, transverse, and in-plane shear directions. The concept was later obtained by determining top tension design for composite risers with fatigue response (Wang et al., 2016, 2017, 2018, 2019). It was discovered that in high strength HS (AS4), failure was dominated by transverse stresses due to matrix cracking, while in high modulus HM (P75), failure was dominated by fibre stresses. Other research investigating strains, stresses, deflection, deformations (displacements), and buckling behaviour has led to advancements in modelling methods, composite theories, and optimization. Thus, it is necessary to optimise risers since sea water areas have chemicals that come from rocks, sea planktons, marine growths, and muds with high saline contents (Peter et al., 2022; Rathnaweera et al., 2016; Ohiara, 2019; Eshiet, 2012). Thus, some research has been done on composite riser prototyping and optimization. Composite risers were designed under different combined loads, and the weights were reduced based on the modelling technique in a study at the University of New South Wales (Wang et al., 2011a, 2011b, 2012a, 2012b, 2015, 2017). An SAEA-based optimization was conducted by Wang et al. (2016) by minimising the weight, and achieved a weight-saving of 25% from the tailored design compared to the conventional method. Amaechi et al. (2019a) presented an optimization approach for the composite riser model by considering five (5) parameters from the finite element model, obtained using maximum stress failure criteria. In the literature, there is some qualification works on composite risers attempting to solve this problem in the composite industry, especially on its reliability, its large-scale production, and its service delivery (Baldwin et al., 1998; Drey et al., 1997; Johnson et al., 1998, 1999; Andersen et al., 1998). Recent advancements in composite riser designs developed by Airborne and Magma Global are noted. Airborne invented some deep-water TCPs (thermoplastic composite pipes) designs (Smits et al., 2018; Echtermeyer and Steuten, 2013; Onna and Lyon, 2014, 2017; Onna and O' Brien, 2011; Steuten and Onna, 2016). Magma Global created composite pipe called M-pipe, utilised in a variety of offshore processes (Roberts and Hatton, 2013; Hatton, 2012, Wilkins, 2016, MagmaGlobal, 2015a; 2016a, 2016b). However, the application has been successful as a hybrid composite riser (McGeorge et al., 2019; Hou et al., 2019; Calash, 2015; MagmaGlobal, 2016c, 2016d; 2016e) but still a challenge in the material modelling and design techniques, thus the need for this present study.

This article presents the tailored local design of a composite riser for application in deep waters, with some parametric investigations on CPR response. The maximum stress failure criterion is utilised on the modelling. The composite riser's rating include high pressure conditions. It is purposed for usage in water depths of up to 2,030 m. ANSYS Composites ACP Pre 2020R2 and ANSYS Composites ACP Post 2020R2 (Amaechi et al., 2019a; Amaechi, 2022; ANSYS, 2017a, 2017b) is used in modelling the composite riser. It was coupled with ANSYS Structural in the finite element model (FEM). The methodology utilised for this finite element method was developed as a multi-layered structure using composite materials, as illustrated in Fig. 2. Five (5) cases for the loadings were applied in this investigation. The length of the riser section modelled is 3.0 m while the diameter of the bore (inner dia.) is 0.250 m. This model procedure involved some numerical stress analysis in ANSYS Composite ACP module. This was conducted with the safety factors for the different loadings. These were conducted along three stress components of the riser section. In this research, three (3) design methodologies are considered-conventional, local and tailored designs for different configurations under burst, collapse, tension, and combined loadings. Different configurations were considered in this analysis, and the structure is made up of configurations having 18 layers, 19 layers and 21 layers. Some parametric studies were conducted using six (6) different materials for the liner and other parameters. This study is aimed at designing CPRs and providing guidance on this novel development for industry specifications and standards. However, current methods use simple beams for global analysis, which is adequate only for steel risers. Thus, vortex induced vibration (VIV) and fatigue response of CPR in global design is recommended but not included in the paper's scope.

Table 1
Parameters for the unidirectional (UD) FRP Composite Riser.

Particulars	Value	Unit
Material	Composites	–
Number of Layers	17, 18, 19, 20 and 21	–
Failure Criteria	Max. Stress	–
Innermost Layer	Liner	–
Outer Diameter	0.3048	m
Length of Riser Section	3.0	m
Ocean Depth	2030	m
Surface Area	7.6605	m^2

2. Model description

2.1. Model description

In this model, the following deep water conditions were taken into account: internal pressure, external pressure, axial tension and combined loads, as given in Section 3.6. In practice, deep water profiles will benefit from the use of composite risers in various platforms. Typical composite riser showing loads in ocean is shown in Figs. 1–2. Various configurations for flexible risers, steel catenary risers (SCR), composite

Table 2
Considerations for material combinations as modelled.

Design Configuration	Liner material	Fibre	Matrix	Design Configuration	Liner material	Fibre	Matrix
Configuration 01	PEEK	AS4	PEEK	Configuration 10	Steel	AS4	PEEK
Configuration 02	PEEK	AS4	Epoxy	Configuration 11	Steel	AS4	Epoxy
Configuration 03	PEEK	P75	Epoxy	Configuration 12	Steel	P75	Epoxy
Configuration 04	PA12	AS4	PEEK	Configuration 13	Titanium	AS4	PEEK
Configuration 05	PA12	AS4	Epoxy	Configuration 14	Titanium	AS4	Epoxy
Configuration 06	PA12	P75	Epoxy	Configuration 15	Titanium	P75	Epoxy
Configuration 07	PVDF	AS4	PEEK	Configuration 16	Aluminium	AS4	PEEK
Configuration 08	PVDF	AS4	Epoxy	Configuration 17	Aluminium	AS4	Epoxy
Configuration 09	PVDF	P75	Epoxy	Configuration 18	Aluminium	P75	Epoxy

Table 3
Material characteristics for Unidirectional FRP lamina.

Parameter/ Description	Fibre volume fraction	Density (kg/m^3)	E_1 (GPa)	$E_2 = E_3$ (GPa)	$G_{12} = G_{13}$ (GPa)	G_{23} (GPa)	σ_1^T (GPa)	σ_1^c (GPa)	σ_2^T (GPa)	σ_2^c (GPa)	τ_{12} (GPa)	$\upsilon_{12} = \upsilon_{13}$	υ_{23}
(APC2) IM7/ PEEK	0.55	1320.0	172.00	8.30	5.50	2.80	2900	1300	48.3	152.0	68.0	0.27	0.48
(V2021) Carbon fibre/Epoxy	0.55	1580.0	10.32	10.32	7.97	3.70	4900	1470	69.0	146.0	98.0	0.27	0.50
(APC2) P75/ PEEK	0.55	1773.0	280.00	6.70	3.43	1.87	668	364	24.8	136.0	68.0	0.30	0.69
(T700) Carbon fibre/Epoxy	0.58	1580.0	230.00	20.90	27.60	2.70	4900	1470	69.0	146.0	98.0	0.20	0.27
(APC2) AS4/ PEEK	0.58	1561.0	131.00	8.70	5.00	2.78	1648	864	62.4	156.8	125.6	0.28	0.48
(S-2) Glass fibre/ Epoxy	0.55	2464.0	87.93	16.00	9.00	2.81	4890	1586	55.0	148.0	70.0	0.26	0.28
(938) P75/Epoxy	0.55	1776.0	310.00	6.60	4.10	2.12	720	328	22.4	55.2	176.0	0.29	0.70
(938) AS4/Epoxy	0.60	1530.0	135.40	9.37	4.96	3.20	1732	1256	49.4	167.2	71.2	0.32	0.46

FRP- Fiber Reinforced Plastics; S-2 – AGY glass fibre; T700– Toray carbon fibre; PEEK- Poly ether ether ketone.
1st subscript - fibre path; 2nd subscript - transverse path; 3rd subscript - in-plane shear path.
Composite ply calculations were on stress components with orientations in these 3 directions called stress directions or stress paths.
υ 1, υ 2, υ 3- Poisons ratio; G12, G13, G23, -Shear modulus; E1, E2, E3 -Elastic Modulus.
HS- High strength; superscript C- compression; superscript T-tension.

production risers (CPR), top tensioned risers (TTR), and offshore hoses (floating, submarine, and reeling hoses) have been engineered depending on the offshore field's needs (Chen et al., 2016; Amaechi et al., 2017; 2019a; 2019b; 2019c). The details on the parameters for the composite marine riser (CMR), on the other hand, are given in Table 1. The CMR is a unidirectional (UD) fibre reinforced polymer (FRP) composite, as detailed in Section 3. It is not specifically carbon-fiber (CF) or glass fiber (GF), because both materials were considered in the investigation. Fig. 1 shows a deep water floating structure under rising water depth, necessitating lighter weight risers as the riser length increases with additional riser segments. Hence, composite risers have been proposed as a possible solution to this problem. Some recent composite riser models have also been developed by some researchers in University of New South Wales and University of Lancaster (Wang et al., 2011a, 2011b, 2012a, Amaechi et al. 2019a). In this present study, a MATLAB file was created for the material model, and it was used in the plot of the finite element analysis from ANSYS ACP (Pre) and ANSYS ACP (Post) (Post). It was used in the comparative analysis as well as in the optimization considerations that were made based on various parameters. Sections 3 and 4 provide information on the orientation, fibre materials, liner materials, thicknesses, and design methodology.

2.2. The design

The design is a key aspect that ensures that the qualification of the composite riser can be achieved (MagmaGlobal, 2016a, 2016b; Hatton et al., 2013; Cederberg et al., 2013; Cederberg, 2011; Baldwin et al., 1998; Drey et al., 1997). Different studies on composite riser material models have been reported (Hatton, 2012; Amaechi et al., 2019a; Alexander et al. 2011). Table 3 gives the characteristics of the composite materials as utilised. As shown in Tables 4 and 5, various liner materials are used. Three methods are considered in this model are listed as follows: the conventional (or traditional or orthogonal) design, the local design, and tailored (or customised) design. The background on each design has been presented analytically in Sections 2.1-2.3. The traditional design is designed using an orthogonal composite technique, in

Table 4
Material characteristics for liners.

Parameter/Description	Poisson's ratio, υ	Elongation at break (%)	Ultimate Stress (MPa)	Yield Stress (MPa)	Elastic Modulus (MPa)	Density (kg/m^3)
(Victrex) PEEK	0.400	45.00	125.0	110.0	4.0	1300.0
HDPE	0.460	10.00	43.0	1350.0	565.0	995.0
(Nylon PA) PA12	0.400	10.00	54.0	1500.0	540.0	1010.0
PVDF	0.400	10.00	54.0	1540.0	550.0	1780.0
(X80) Steel	0.300	5.90	950.0	880.0	207.0	7850.0
(1953T1) Aluminium alloy	0.300	7.50	540.0	480.0	71.0	2780.0
(Ti6Al4V) Titanium alloy	0.342	14.00	950.0	880.0	113.8	4430.0

PEEK- Poly ether ether ketone; HDPE- High Density Poly ethelene; PVDF -Polyvinylidene fluoride; PA12-Polyamide 12.

Table 5
Convergence study on the FEA.

Runs	Circumferential Divisions	Axial Divisions	Elements Statistics	Nodes Statistics	Transverse Stress {1st layer axial}	Fibre Stress {2nd layer axial}	In-plane Shear Stress {7th layer axial}	Transverse Stress {14th layer axial}
01	80	30	2400	16950	20.8857	39.8865	38.9907	29.584
02	80	40	3200	22600	20.9098	40.2943	38.9572	29.654
03	80	50	4000	28250	20.9209	40.483	38.9416	29.6862
04	80	60	4800	33900	20.9269	40.5853	38.933	29.7037
05	80	80	6400	45200	20.9328	40.6873	38.9245	29.7211
06	80	100	8000	56500	20.9356	40.7345	38.9206	29.7291
07	80	120	9600	67800	20.9371	40.7602	38.9185	29.7334

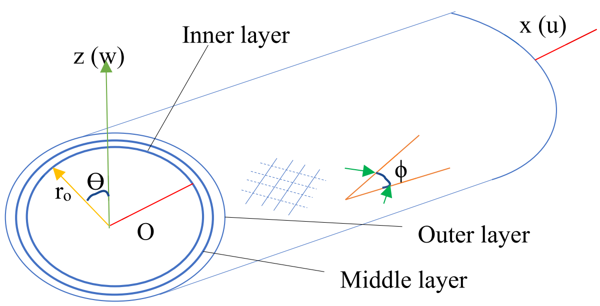

Fig. 3. Nomenclature for the different plies of marine composite riser.

which laminate plies are patterned in two directions. The ply patterns in this riser model are 0° and 90° orientations. The composite riser's reinforcements are built in three directions: axial, off-axis (or angled), and hoop. These are the fibre path, transverse path, in-plane path, and out-of-plane path, as shown in Figs. 4 and 5. However, the local design was based on the fibre path, the transverse path, and the in-plane path, while the traditional design was based on the fibre path and the transverse path. The stress on an element from the composite riser model was calculated and recorded with great care. The rosette of each component in ANSYS ACP has different directions (or paths) for the stress components. The design parameters studied include the lamina thicknesses, composite riser diameter, and material weight in this study. Governing equations with analytical models on cylindrical composite pipes are available in the literature (Ye, 2003; Jones, 1999; Kaw, 2006; Xia et al., 2001; Sun and Li, 1988). The limit criteria considered in this study was maximum stress.

2.3. Netting theory

Netting theory is described as a technique for simulating the stresses in the hoop path cum the axial path under burst load as considered for the composite riser pipe illustrated in Fig. 3. This method applies some assumptions, including the fibres in the laminate, not the matrix, support all stresses exerted on the tubing. The premise of this theory includes the existence of uniform tension along the fibre direction, although, in contrast, the transverse direction presents the absence of any in that stress component. By applying Netting theory relationships as detailed in literature (Gillett, 2018; Amaechi et al., 2019a), the netting theory was used to obtain the best angles for helical wound off-axis fibres to be $\theta = \pm 54.7°$. In this modelling, netting theory was considered in the determination of the angled plies. From this study, the off-axis (angled) plies were obtained to be best at ±53.5° through the approach of Netting Theory, and was compared with the results from the optimized model, and that result of angled plies of ±54.5° from validated studies (Amaechi et al., 2019a, Gillett, 2018). The netting theory was chosen because it is a well-established composite theory that has been successfully applied to composite materials in the literature (Hossain et al., 2013; Gillett, 2018; Evans and Gibson, 2002; Amaechi et al., 2019a; Tew, 1995). The fibres that are load-bearing along the respective layers are assumed to have the capacity to bear loads in netting theory, but there are no stresses in the transverse direction (Gillett, 2018; Amaechi et al., 2019a; DOD, 2002).

3. Materials and methodology

3.1. Material properties

In Section 2, theory on the stress and deformation of composite risers and composite tubes were presented analytically. The geometrical parameters considered in the design stage are tabulated in Table 1. Table 2 spells out the considerations for the material combinations of the CPR

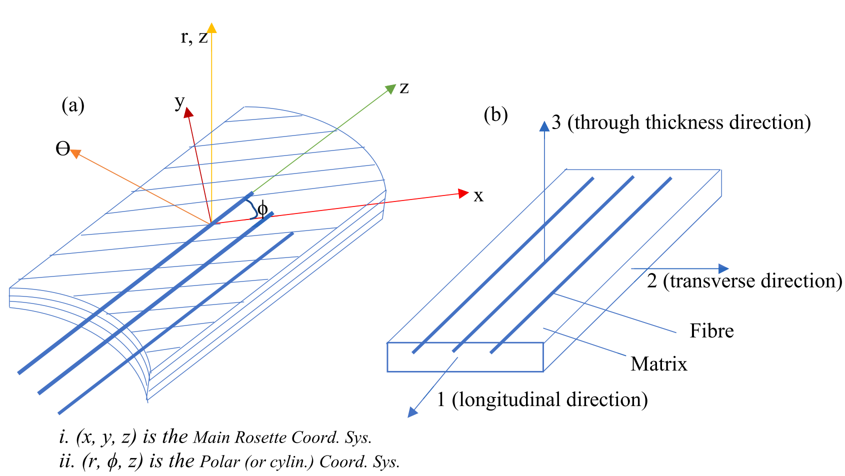

Fig. 4. Representation of (a) Cylindrical coordinate and material (or rosette) principal coordinate systems, and (b) Rosette (or Lamina) co-ordinate system showing the stress directions.

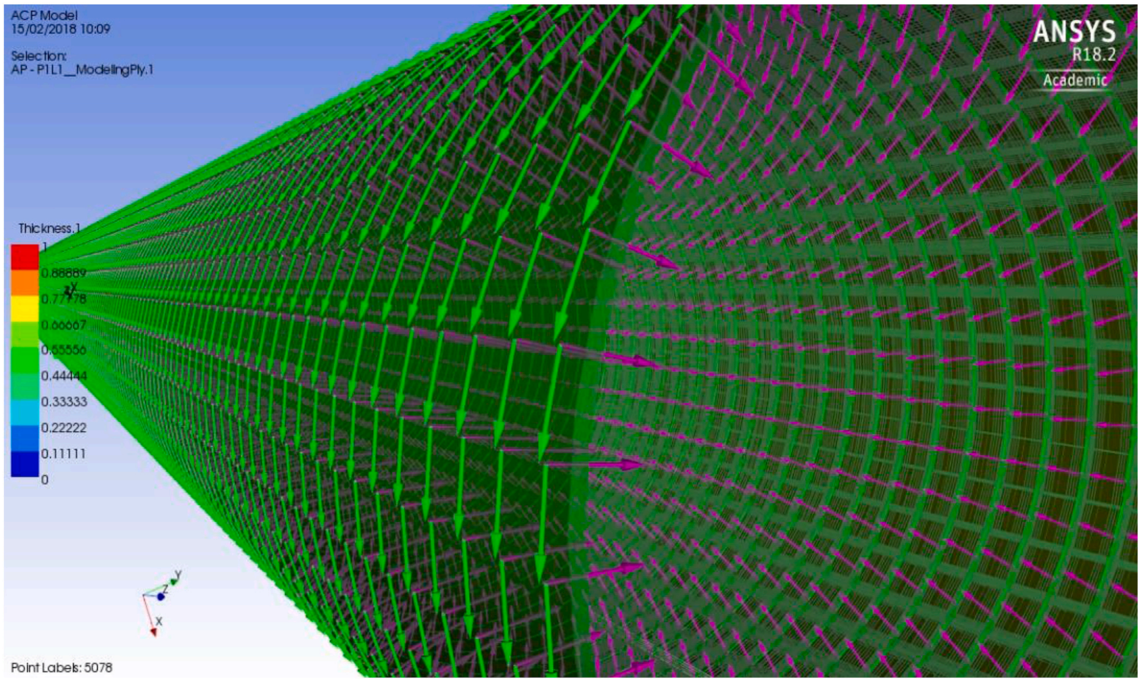

Fig. 5. Parametric composite riser lay-up showing the fiber and laminate in ANSYS ACP.

Table 6
The Design Loadings for modelling the Composite Riser.

Design Load	Parameters	Detailed Information of Load
Loading 01	Tension	Using factor of load as 2.25 and tensioned maximally
Loading 02	Internal Pressure (Burst) + effect of load at ends	Using int. press. at 155.25 MPa was utilised
Loading 03	External Pressure (Collapse)	Using ext. press. at 60.00 MPa was utilised
Loading 04	Combined - Tension plus Internal Pressure	Using int. press. at 155.25 MPa and tensioned
Loading 05	Combined - Tension plus External Pressure	Using a factor of load as 2.25 for 19.50 MPa ext. pressure

model are detailed in Sections 3.1.1-3.1.2. However, to prevent the liner and the metallic parts from debonding, the PEEK, PA12, and PVDF liners were considered using high modulus P75/PEEK and AS4 PEEK. Details for each of the three design approaches on the stacking series, laminate layer thicknesses, liner thicknesses, and fibre orientations are given in Tables 7–9. Both the fibre and matrix combinations are made of high-performance materials. Tables 3 and 4 provide the mechanical characteristics of the materials selected in this design. By considering the material characteristics and mechanical performance, a variety of materials have been presented and utilised in this investigation. This riser is treated as a conduit tubular with thick walls, as shown in Figs. 5 and 6. The mechanical behaviour of the materials is taken into account during the modelling procedures. In addition to in-plane effective properties, the composite riser has other material properties. The layer thicknesses and mechanical attributes of the materials applied while modelling is tabulated in Tables 2–4. These information were gathered via various verified scientific authorities as referenced in earlier publications (Amaechi et al., 2019a; Wang et al., 2011a, 2012a, 2017, Singh, 2014; Hartman et al., 1996) and technical data sheets (Toray, 2008; MatWeb, 2018, 2021a, 2021b, 2021c; Solvay, 2017). These selected composite materials were also validated for the composite riser modelling, using verified material modelling techniques (Ye et al., 2021, Chesterton, 2020; Amaechi et al., 2019a, Gillett, 2018, Ye, 2016, 2003), as utilised for the model shown in Fig. 7.

Table 7
Geometry and orientation of the $[90/(0/90)_4]$ composite plies for conventional design.

Ply/ Layer	Name of Layer	Inclination Angle/Orientation (°)	Thickness (mm)
00	The Liner		2.00
01	Hoop Layers	90	1.62
02	Axial Layers	0	1.58
03	Hoop Layers	90	1.62
04	Axial Layers	0	1.58
05	Hoop Layers	90	1.62
06	Axial Layers	0	1.58
07	Hoop Layers	90	1.62
08	Axial Layers	0	1.58
09	Hoop Layers	90	1.62
10	Axial Layers	0	1.58
11	Hoop Layers	90	1.62
12	Axial Layers	0	1.58
13	Hoop Layers	90	1.62
14	Axial Layers	0	1.58
15	Hoop Layers	90	1.62
16	Axial Layers	0	1.58
17	Hoop Layers	90	1.62
18	Axial Layers	0	1.58
19	Hoop Layers	90	1.62
20	Axial Layers	0	1.58
21	Hoop Layers	90	1.62

3.1.1. *Determining composite lamina properties*

The determination of composite lamina properties are performed, as presented in this section. Mechanical testing on unidirectional laminate samples can be used to assess the material properties of fibre-reinforced unidirectional laminae, although this is time consuming (Ye et al., 2021, 2020; Wang et al., 2017; Cai et al., 2020; Wan et al., 2020). In this study, 3D solid elements are used in the FEA of composite tubulars for local design as shown in Fig. 7, which necessitates specifying their strength and stiffness qualities in all directions. However, determining all of these qualities experimentally would be prohibitively time demanding and would detract present study's principal goal of demonstrating the

Table 8
Lay-up with ply inclination angle for local design.

Ply/ Layer	Name of Layer	Inclination Angle/ Orientation (°)	Thickness (mm)
00	The Liner	0.0	2.00
01	Axial Layers	0.0	1.58
02		0.0	1.58
03		0.0	1.58
04		0.0	1.58
05	Angled Layers (or Off-axis Layers)	53.5	1.86
06		−53.5	1.86
07		53.5	1.86
08		−53.5	1.86
09		53.5	1.86
10		−53.5	1.86
11		53.5	1.86
12		−53.5	1.86
13		53.5	1.86
14		−53.5	1.86
15	Hoop Layers	90.0	1.62
16		90.0	1.62
17		90.0	1.62
18		90.0	1.62

Table 9
Geometry and orientation of the $[\pm69/69/90_8/\text{-}69/(\pm69)_2,0_3]$ composite plies for tailored design.

Ply/ Layer	Name of Layer	Inclination Angle/Orientation (°)	Thickness (mm)
00	The Liner		2.00
01	Angled Layers	69	1.86
02		−69	1.86
03		69	1.86
04	Hoop Layers	90	1.58
05		90	1.62
06		90	1.62
07		90	1.62
08		90	1.62
09		90	1.62
10		90	1.62
11		90	1.62
12	Angled Layers	−69	1.86
13		69	1.86
14		−69	1.86
15		69	1.86
16		−69	1.86
17	Axial Layers	0	1.58
18		0	1.58
19		0	1.58

suggested tailored design of laminated composite risers, determining the model configurations, and quantifying the weight reductions that may be realised by the design. As a result, using the laminae parameters are extracted from manufacturer's specifications or research publications is deemed appropriate and sufficient (Singh and Ahmad, 2014; Wang et al., 2015, 2017). However, because it is difficult to locate all of the 3D mechanical characteristics of composite laminae in the literature, they must be calculated analytically using the values of the constituent materials, fibres, and matrices obtained by micromechanics. Since the nine elastic constants of the 3D unidirectional lamina computed using various theoretical models generate slightly varying values, these data are taken using previously published results whenever possible in choosing the most accurate polls.

3.1.2. Rule of mixture (ROM)

Some matrix mix calculations were used to determine the rule of combination and the final laminate material parameters in Table 2. The Rule of Mixtures is a method for estimating composite material qualities that is based on the idea that a composite property is the volume weighed average of the phases' attributes (matrix and dispersed phase). The properties of composite materials are estimated using the Rule of Mixtures: Poisson's ratio, Shear modulus, Elasticity Modulus, Ultimate Tensile Strength, Coefficient of Thermal Expansion, and Density terms used to describe the properties of a material. It gives these qualities a theoretical upper- and lower-bound. Such a technique is far more erroneous for predicting the strength of a composite, because the strength is largely dependent on the quality of the link between the matrix and the fibre. Furthermore, final failure does not always correspond with the commencement of damage in a laminate made up of numerous layers with varied fibre orientations. Damage might begin at a load that is substantially lower than the final failure load. However, modelling of the matrix and fibres is required to anticipate when damage begins and progression mode, in the micro-mechanics of composites (Ye et al., 2021, 2020, Chen et al., 2021a; 2021b, Sharma et al., 2020). Maximum Stress and Strain Failure Theories, Tsai-Hill Failure Theory, and Tsai-Wu Failure Theory are more simple theories but still evolved ways to forecast the strength of composite laminates compared to the rule of mixtures. The rule of mixtures is a very simple and reasonably accurate way of predicting the stiffness of a composite based on the volume fractions of the constituents (i.e. fibres and matrix) and their corresponding stiffness. The rule of mixture considered for the materials in Table 2 were based on design considerations. In Fig. 4, the lamina coordinate system is given, and it should be noted that the lamina attributes are significantly reliant on the fibre volume fraction (FVF) or fibre volume ration (V_f), which must be carefully selected. Assuming that all the fibres are aligned in one direction, the stiffness of the composite can be calculated as follows:

$$E_c = E_f V_f + E_m V_m \tag{1}$$

$$\rho = \rho_f V_f + \rho_m V_m \tag{2}$$

Where E_f is stiffness of the fibres, V_f is volume fraction of the fibres, E_m is stiffness of the matrix, V_m is volume fraction of the matrix, ρ_f is density of the fibres, and ρ_m is density of the matrix, are available in literature (Ye, 2003, Altenbach et al., 2004; Gillett, 2018). Details on the ROM formulation considered in this investigation are not included in the scope of the present study.

3.2. Methodology

In this paper, three design methodologies are considered-conventional (or traditional or orthogonal) design, local design, and tailored (or customised) design. The model was developed for different configurations under burst, collapse, tension, and combined loadings. The parameters in Table 1 are used in this paper's design methodology. The angles for the plies are **0**° and **90**° orientations in the conventional system. The composite riser's reinforcements are built in three directions: axial, pointed, and hoop. Details of the lay-ups are given in Tables 7–9 The material characteristics of these composites under consideration, as given in Table 3, were applied. As shown in Table 4, various liner materials are used. The design phase from the stage of development of the computer-aided design (CAD) model using the CAD module called ANSYS Design Modeler R2 2020. Then, in the interface of the ANSYS Workbench, other modules are linked to the geometry module, as detailed in Sections 3.3-3.4. In the modelling, an optimization was conducted by using design of experiments (DOE) method and a response spectrum algorithm. The lowest weight was considered in this study, and the study results are given in Section 4. The stress analysis of the CPR is regarded following traditional stress analysis (Ye, 2016, 2003; Qin and Ye, 2015, Ye et al., 2020, 2021).

3.3. Finite element analysis (FEA)

The framework for this numerical investigation focuses on designing a novel composite tubular structure model for composite marine risers.

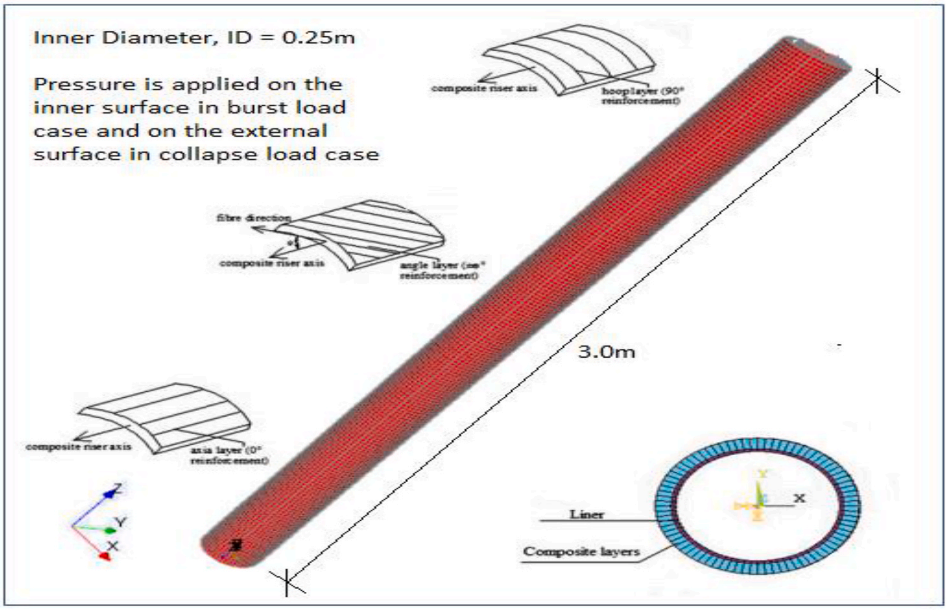

Fig. 6. The FEA model developed for the composite tubular structure depicting layers and the coordinate plane.

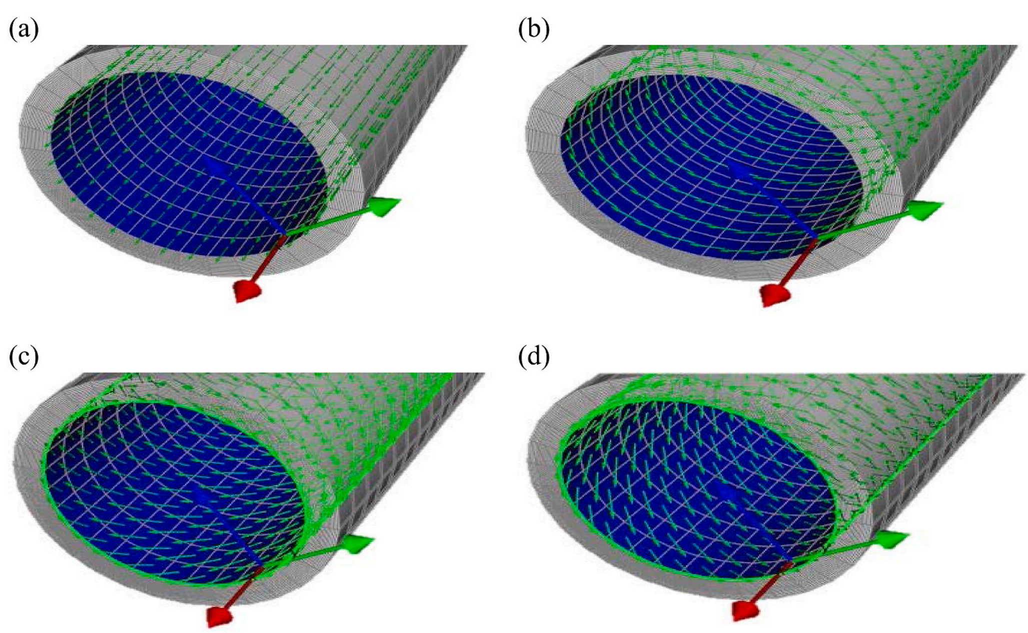

Fig. 7. FEM for composite ply arrays and the rosette in ANSYS ACP (Pre) R2 2020 at: (a) 0°, (b) 90°, (c)+53.5° and (d) −53.5°.

Finite Element Method (FEM) is the computational technique utilised in this design. ANSYS ACP was used to build the composite riser model. Table 1 lists the parameters for the composite production riser. Section 3.6 details the loading conditions, the boundary conditions and design methodology, which are fully discussed. It was fixed at both ends for the burst and collapse conditions. The boundary conditions were fixed at both ends but detailed in Section 3.6. The limit criteria considered in this present study was maximum stress. However, some end considerations were added at one end to efficiently obtain the burst values. The meshing was conducted by divisions. Based on the statistical makeup of the elements, the ratio of the circumferential divisions to the axial divisions applied is 80:30. The FEA model has 16,950 nodes and 2400 component elements in ANSYS ACP 2020 R2.3D structural-layered solid elements called Solid 186 elements were used in the modelling. This sort of element allows for quadratic displacements along three degrees of freedom (3DoF) with translation motion around its 20 nodes. Solid 186-homogenous elements are used to simulate single elements in the radial direction, such as the liners. However, this does not composite plies. Solid 186-layered elements are utilised to simulate the composite riser's plies. The nodal coordinates are used by the solver to apply the element's thickness. This aids in the setup for both the plies and lay-up. As a result, the entire lay-up is created in a defined material coordinate (or rosette). The load cases were used to get stress values for each composite layer for various thicknesses as part of the local design technique. As shown in Tables 7–9 and Fig. 8, it can be observed that the layered structure has different arrangements based on the design. Fig. 8 shows a finite element model in ANSYS ACP (Pre) as configured in the lay-up (or stack-up) arrays. In Fig. 8(a) the stackup for the local design has 18 layers for the $[0_4,(53.5)_5,90_4]$ configuration, while in Fig. 8(b), the stackup for the conventional design has 20 layers for the $[90/(0/90)_4]$

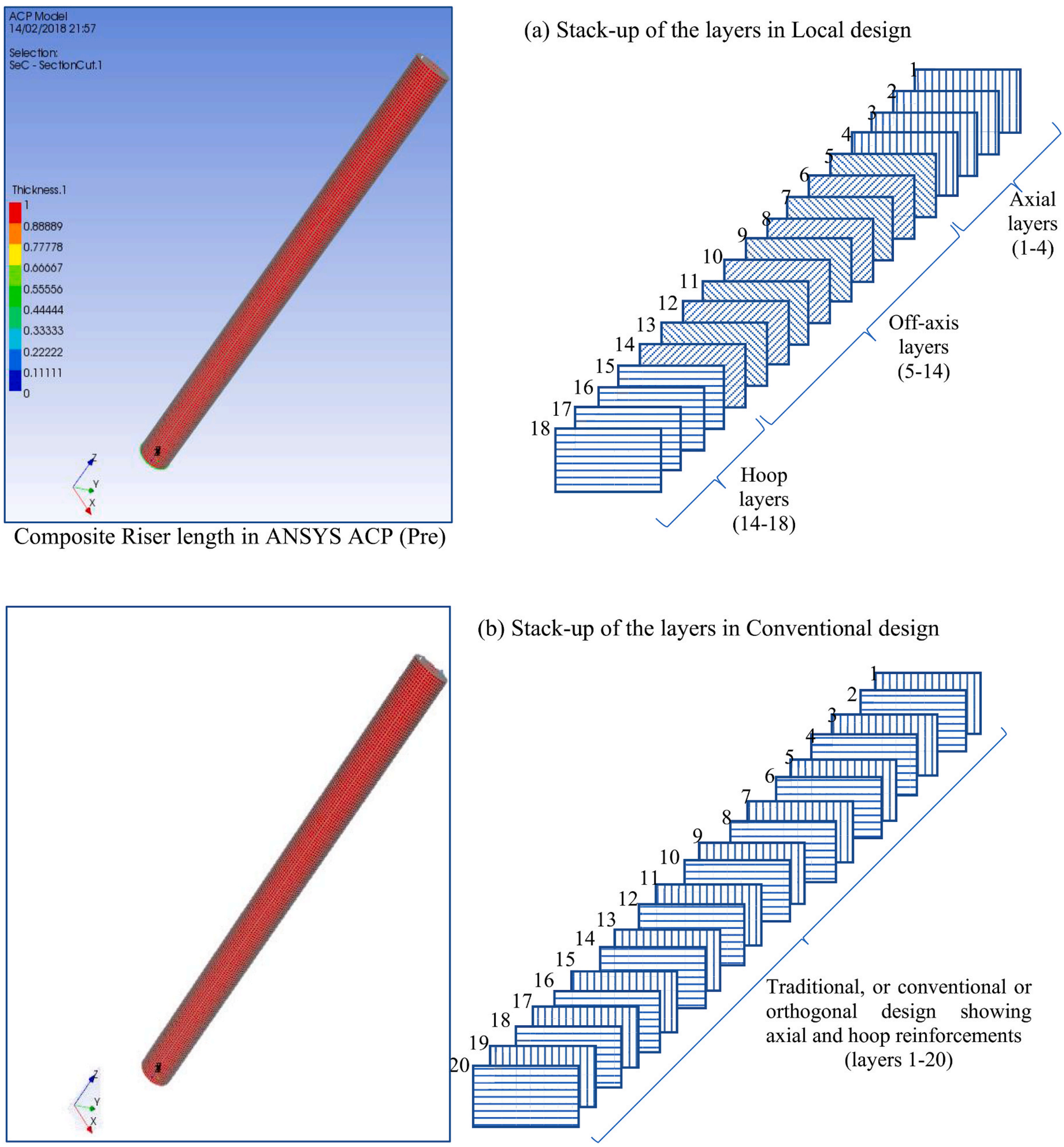

Fig. 8. FEM of the Composite Production Riser model showing parametric stack-up of layers for two designs.

configuration. The axis for the layers of the material in this design is constructed towards the layer that is innermost from the layer that is outermost.

3.4. *Material setup & lay-up*

The material lay-up took up a significant amount of time during the design process. For different composite riser orientations, the lay-up was constructed differently. As seen in Figs. 2 and 8, each orientation had its unique lay-up or stack-up series. Table 4 shows the stack-up series for the plies (or layers) and the fibre orientations for the composite riser structure. Two methods were applied in the computer-aided design procedure. The first was to generate the geometry in Solidworks 2020, followed by the uploading the model in ANSYS Workbench. The second method was to generate the model in ANSYS Design Modeler R2 2020. The second method was adopted as it made the model easier to use in model development and parametric studies by changing the parameters during the modelling. An important model is the geometry model for the composite riser. ANSYS Workbench 2020 R2 was used to create the Mechanical Model. The Engineering Data Module was used to *'create'* the material properties, and then the model was developed. The module was then linked to a Static Structural module, which was used to create a new composite material model. The second element involved creating a new setup with the same geometry. Different liner thicknesses were formed in this section. The material properties were then established using the composites module, ANSYS ACP (Pre) and ANSYS ACP (Post) modules. The results were obtained from the created model and post-processed, after both modules were related in the interface on ANSYS Workbench. The ACP (Post) was where the findings could be visualised and extracted. Without the need for device coupling, the two ANSYS Composites modules were then attached to an ANSYS Static Structural module. Using the loads in Section 3.6, different design scenarios were investigated on. This procedure was followed in order to achieve the composite riser design's *'optimal model'* or the *'best-working model'*. The

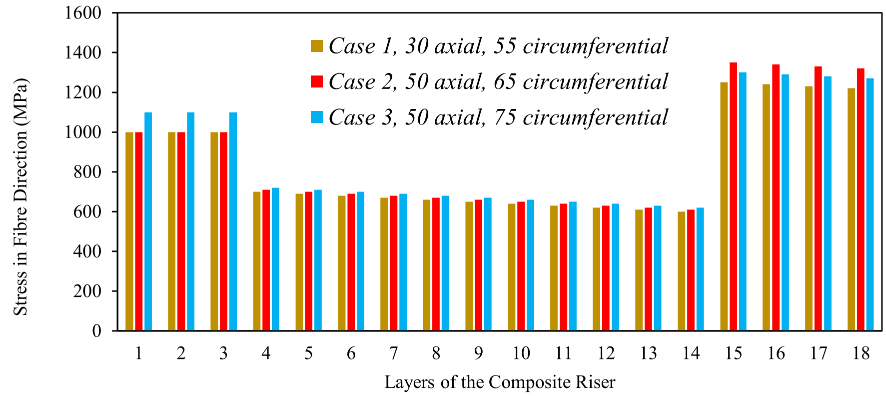

Fig. 9. Mesh study using different mesh number of divisions by utilising Aluminium liner combined with AS4/Epoxy and configured on $[0_4,(\pm 53.5)_5,0_4]$ model.

development process to achieve the most effective model takes into account axial reinforcements, angled reinforcements, and hoop reinforcements. Using Netting Theory, the off-axis (angled) plies were calculated to be +53.5, as discussed in Section 2.5. By applying this modelling method outlined, similar to that in Amaechi et al. (2019a), the Safety Factors (F.S) per layer were obtained and recorded, as presented in Section 4.

3.5. Mesh analysis

Meshing is used in the numerical model of the composite structure. It is an aspect of the finite element model. The aim of the study includes to have gains on the computational resources while applying the best mesh statistics. The mesh details for the FEA as shown in Table 5, were used to conduct a convergence analysis. In Fig. 9, any earlier mesh analysis is conducted. It can be observed that the *mesh_case01* having 75 circumferential divisions and 50 axial divisions has the highest stresses along the fibre path for the axial lamina, while there was similar stresses along the fibre path (or direction) for the axial lamina (or layers) for both *mesh_case02* having 55 circumferential divisions and 30 axial divisions and *mesh_case03* having 65 circumferential divisions and 50 axial divisions. However, in the transverse directions, the highest is *mesh_case03* followed by *mesh_case03* and then the least is *mesh_case03* however, they are very close in the angled layers. For the in-plane shear direction, the *mesh_case02* is the highest followed by the *mesh_case03* and the least is the *mesh_case01*. It can be inferred that the best size of the meshes among these 3 mesh run cases are the mesh sizes with 50 axial divisions, but the higher circumferential divisions had more effect on the axial layers than on the hoop layers. As such a detailed convergence study is recommended, as presented in Table 5. The results were recorded at the axial layers with an angle of **0**° for the 1st, 2nd, 7th and 14th layers, respectively along different stress components as tabulated. The mesh analysis compares the elements statistics to different components of stress. It was taken at the liner next to the innermost ply. The size of the mesh in *mesh_run01* on Table 5 was used in the analysis based on the data. It was chosen based on the stress distribution along these components that were chosen as tabulated. Additional investigation on the effect of mesh divisions on a stress profile that was carried out, as presented in Fig. 9 also showed good correlation. In conclusion, this study shows good convergence as presented in the results in Table 5, which exhibits high level of convergence.

3.6. Local design loads

The loadings on a standard composite riser was used to build the model, as illustrated in Fig. 2. The local architecture took into account five (5) separate load scenarios, as shown in Table 6. The burst case is denoted the design load 1, and it is the most important load case, and it was often looked into first. The design loads were implemented according to the requirements for the designing these risers in the offshore-marine industry using composites (ABS, 2017; DNV, 2010a, 2010b, 2013; DNVGL, 2015). In a study conducted on composite risers, 2.25 is the load factor obtained and recommended based on experimental test as stated in the industry standard (ABS, 2017). This is the ultimate strength for the tension of composite risers, as applied in the present study to ensure that tension is properly modelled. This method has also been applied on literature (Amaechi et al., 2019a, 2022d, Gillett, 2018; Wang et al., 2011a, 2012b) The different stress components for each of the different fibre orientations were also included in the design considerations for the stress distributions obtained are discussed in Section 4. It is noteworthy to state that the justification for choosing these load cases, were based on preliminary design, and they are the key ones to

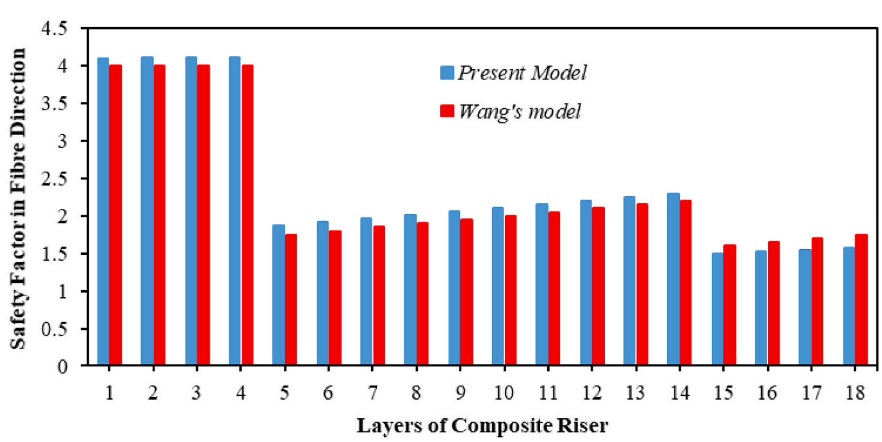

Fig. 10. CPR Model Validity studies during Internal Pressure for models by Amaechi (present) and Wang (compared).

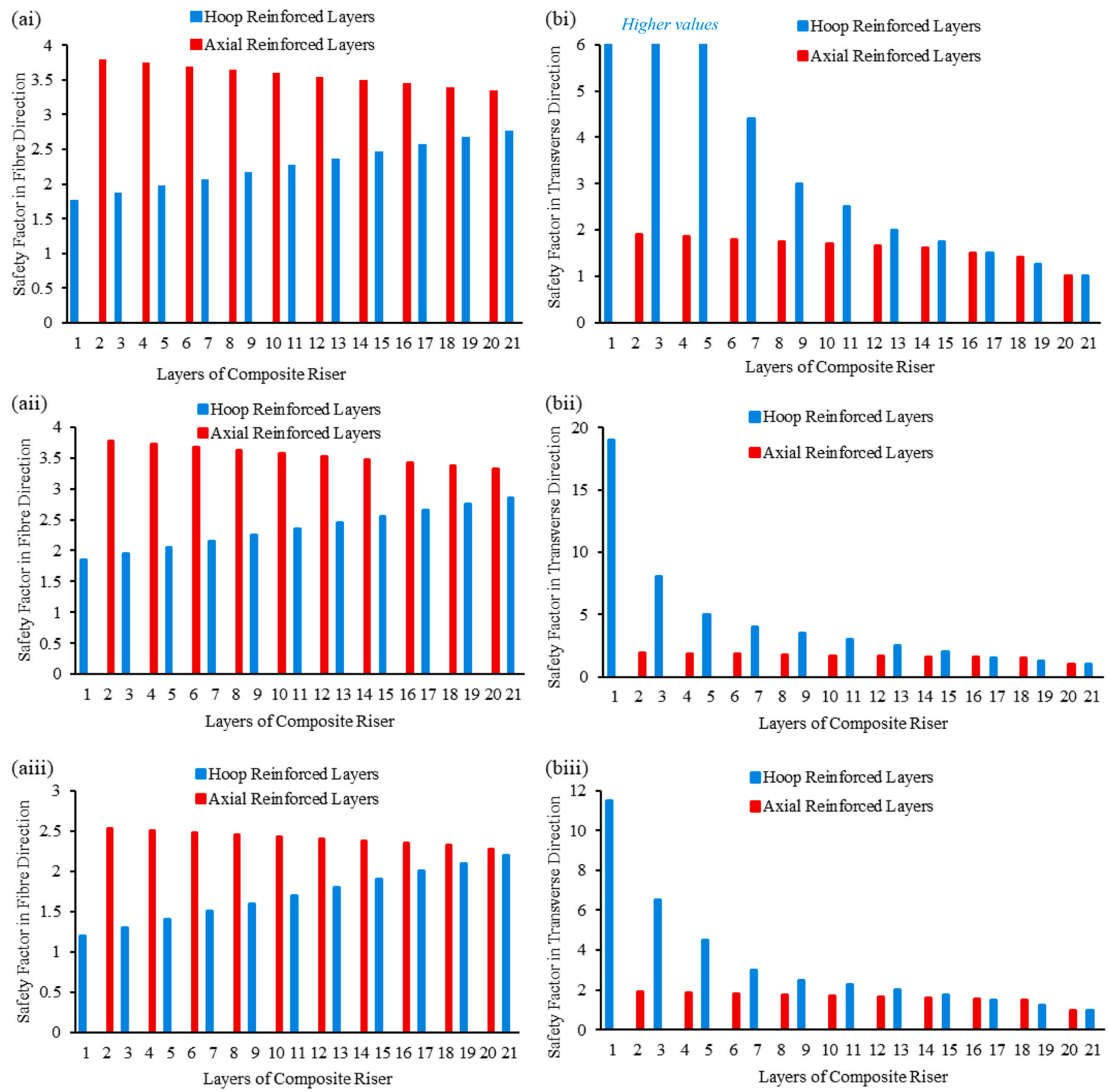

Fig. 11. Safety Factor distribution of composite layers under burst loadings for: i) Aluminium liner with AS4/Epoxy configured on $[90/(0/90)_4]$ showing (a) Fibre and (b) Transverse Directions; ii) Titanium liner with AS4/Epoxy configured on $[90/(0/90)_4]$ showing (a) Fibre and (b) Transverse Directions; and iii) PEEK liner with AS4/PEEK configured on $[90/(0/90)_4]$ showing (a) Fibre and (b) Transverse Directions.

check but not all the loads to design for on a CPR, based on industry specifications in ABS (2017) and DNV (2010a) standards. Thus, designing based on these conditions only is limiting, but presented due to the length and the scope of the paper too. This, marine riser designers are recommended to understand that there are other load cases for a much-detailed study on a CPR.

3.7. Validation

To ensure the validity of this composite riser model, a comparison was made with the results obtained on this investigation, and they were verified with studies obtained via literature (Amaechi et al., 2019a, Wang et al., 2011a, 2011b, 2012a, 2012b, 2015). Both models were used as presented in Fig. 10. The validation of the model was investigated for burst load in fibre direction using Aluminium liner and AS4/Epoxy with a layup arrangement of $[0_4,(\pm 53.5)_5,0_4]$. The three-dimensional model was established using this model. In contrast to Wang Chunguang's model, which was also validated in Amaechi et al. (2019a), the present model has a higher S.F than Chunguang's model. It was observed to be a result of a notable fact that Wang Chunguang's models use a different approach (homogenization) and has variation in the number of divisions in the meshing process. The ratio of divisions for the circumferential to the axial, is 80:150. In addition, the modelling methods used differ; the current model was created with ANSYS ACP, while Wang's model was

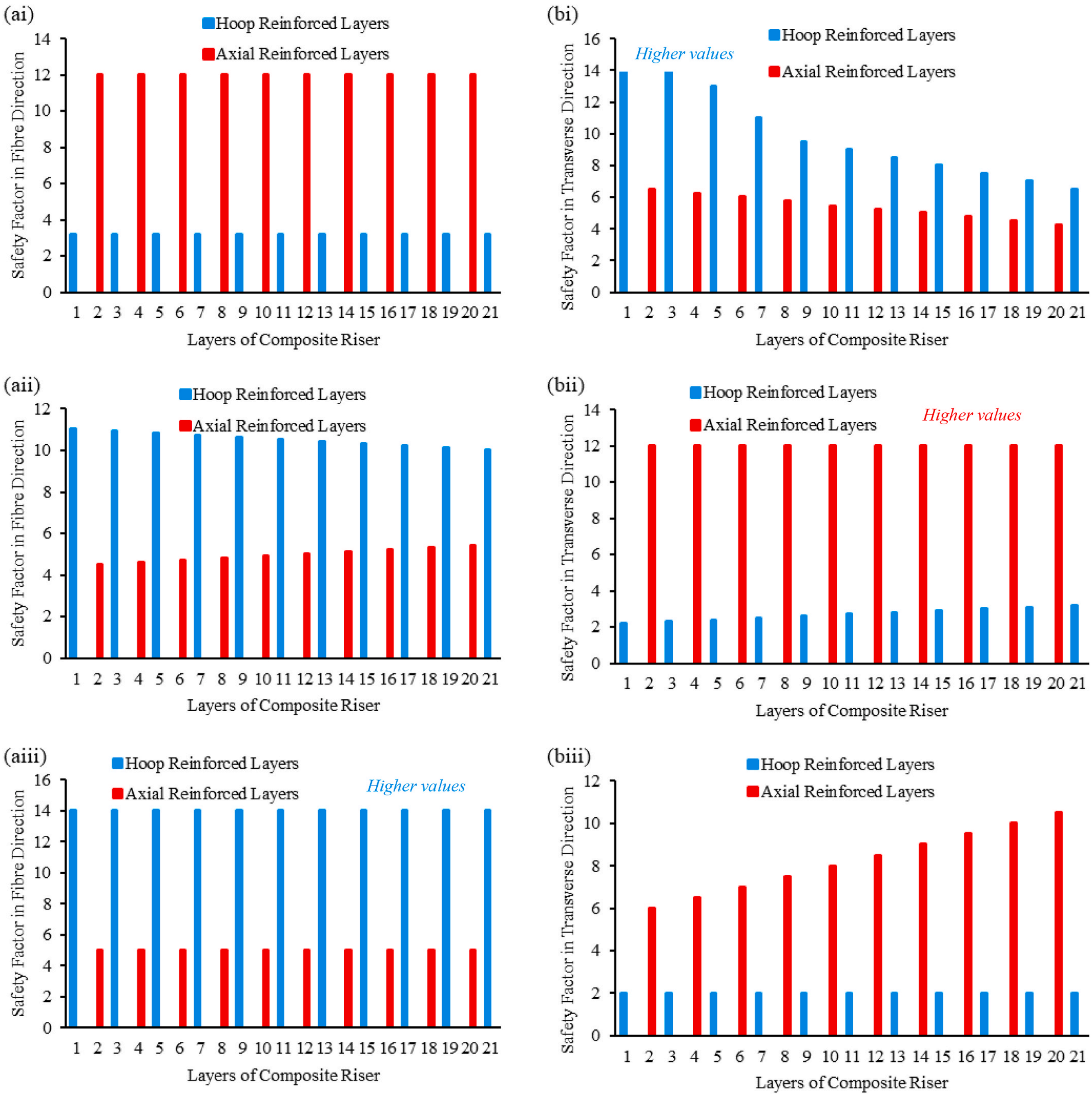

Fig. 12. Safety Factor distribution of composite layers under: i) collapse loadings along (ai) Fibre and (bi) Transverse Directions; ii) tension plus external pressure loadings along (aii) Fibre and (bii) Transverse Directions; iii) pure tension loadings for (aiii) Fibre and (biii) Transverse Directions, by utilising Aluminium liner and combining AS4/Epoxy configured on $[90/(0/90)_4]$.

created with ANSYS APDL. Lastly, there are variations in the thicknesses of the layers between both layers but with close deviation in thicknesses. As a result, there is strong agreement between the two models, confirming the consistency of the current model's findings. Furthermore, there is some correlation between the layers, which indicates model validity and suggests that the current model is correct, and well validated.

3.8. Global design loads

Preliminary local design based on critical local load cases (LCs) and global study of the entire length composite riser under global loads are performed. In principle, the global loads include platform motion, hydrostatic pressure, gravity, buoyancy, wave, and current to establish and analyse critical locations (Amaechi et al., 2019a, 2019e; Bai and Bai, 2005; Sparks, 2018; Saleh, 2015). Also, the prediction of adequate loads and responses of the structure due to the combined action of all applicable forces, as well as its strength enhancement, are key considerations in composite riser design. The global design is discussed further based on comparative analysis with composite riser similar to riser configurations developed on composite marine hose models in other studies (Amaechi et al., 2019e, 2019f; Amaechi, 2022). Global design is not included in the present study but in separate research literature by author.

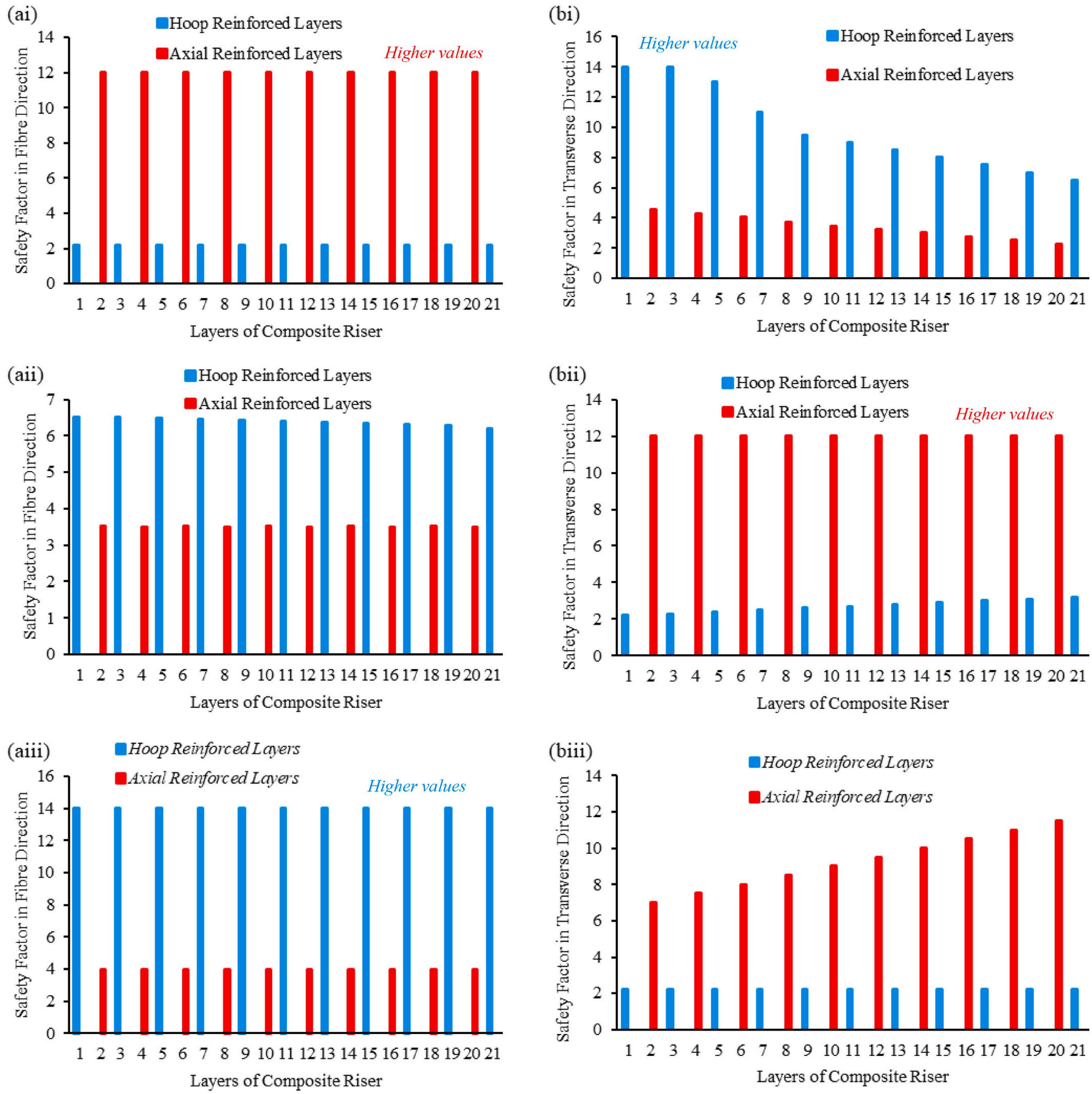

Fig. 13. Safety Factor distribution of composite layers under: i) collapse loadings along (ai) Fibre and (bi) Transverse Directions; ii) tension plus external pressure loadings along (aii) Fibre and (bii) Transverse Directions; iii) pure tension loadings along (aiii) Fibre and (biii) Transverse Directions, by utilising PEEK liner and combining AS4/PEEK configured on $[90/(0/90)_4]$.

4. Results

4.1. Result of design models

4.1.1. Result of conventional design

The results on the conventional design are presented in Figs. 11–13. Fig. 11(a–i) shows the results from the burst loadings for the conventional design, with geometry considered in Table 7. It also presents the thicknesses and orientation of the $[90/(0/90)_4]$ Composite Plies considered in the Conventional Design. The composite model was designed in ANSYS Composite ACP R2 2020 with three-dimensional elements. The findings from the numerical analysis covered deflections along the different stress components. Since these results fall below the ABS (2017) standard's S.F limit value of 1.0, then it is a suitable model. That implies that the designed model meets the criteria. To have a working structure that has the most efficient, the design should be engineered following the design procedure presented earlier. However, it must be checked for safety qualification by calculating the Safety Factor by applying the material strength properties tabulated in Table 3. The S.F can be calculated by applying the expression in Equation (26). For the sake of scientific clarity, the Safety Factor (S.F) is the same as the Factor of Safety (F.S), as considered in literature (Gillett, 2018; Amaechi et al., 2019a).

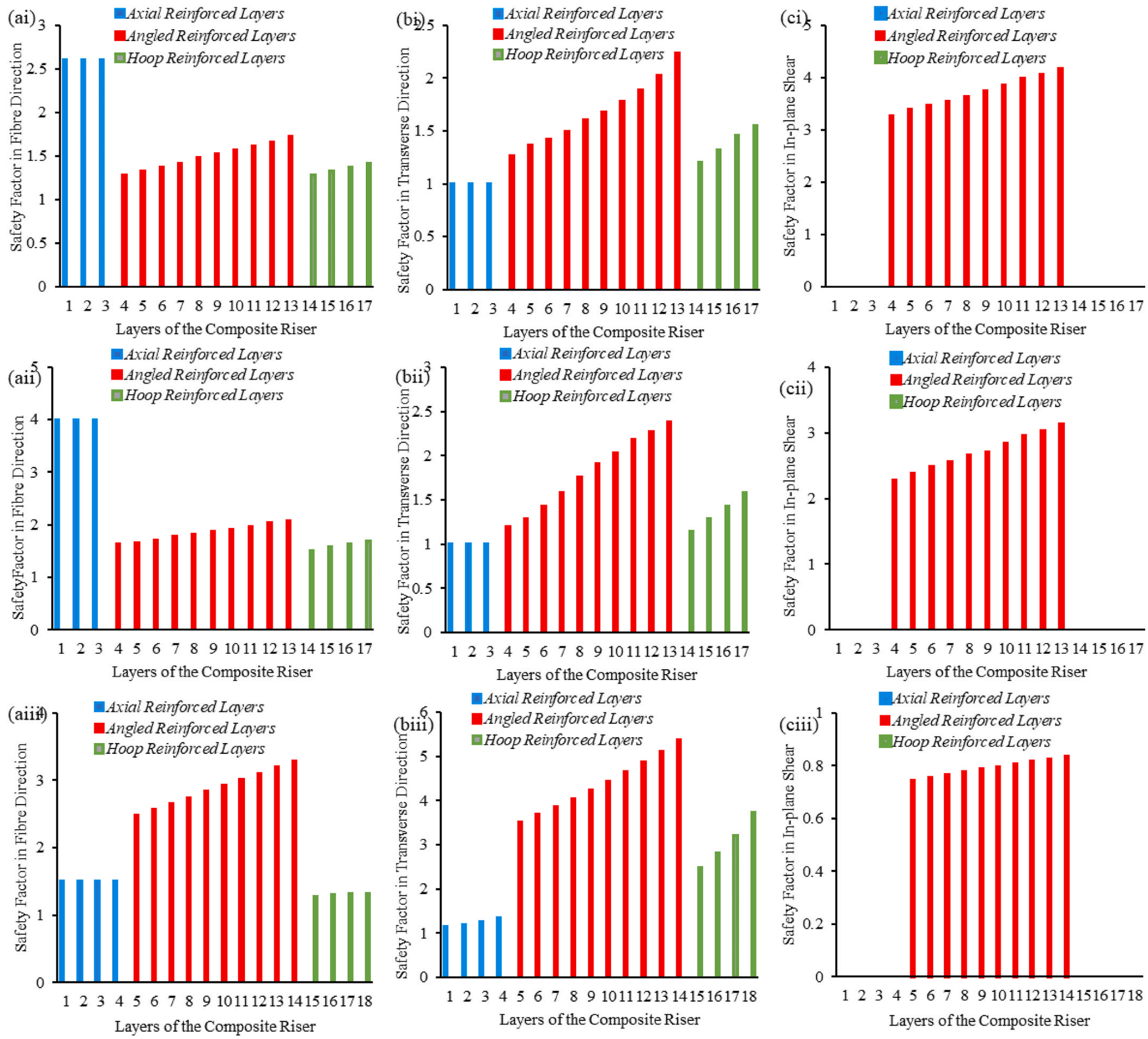

Fig. 14. Safety Factor distribution on: i) PEEK liner combining AS4/PEEK configured on $[0_3,(\pm 53.5)_5,90_4]$ along (ai) Fibre, (bi) Transverse and (ci) In-plane Shear Directions; ii) Titanium liner combining AS4/Epoxy configured on $[0_4,(\pm 53.5)_5,90_4]$ for (aii) Fibre, (bii) Transverse and (cii) In-plane Shear Directions; iii) Titanium liner combining AS4/Epoxy configured on $[0_3,(\pm 53.5)_5,90_4]$ along (aiii) Fibre, (biii) Transverse and (ciii) In-plane Shear Directions; all from burst loadings.

$$\text{Safety Factor } (S.F) = \frac{\text{Allowable Strength } (\text{or yield strength})}{\text{Actual Strength } (\text{or working strength})} \quad (3)$$

The conventional design was carried out to observe the effect of including the angled plies in the FEA. For the conventional design, three different configurations were investigated under the critical load case-burst loadings. It was found that the AS4/Epoxy with Aluminium liner was the weaker configuration while the AS4/PEEK with PEEK liner was the stronger configuration. However, it was also necessary to investigate this further by including composite materials in off-axis or angled orientations, to improve the mechanical performance of the modelled riser. Also, as observed in Fig. 11 [a(i), a(ii), a(iii)] for the fibre direction for the three cases, the S.F limit value of 1.75, 1.85 and 1.2 were recorded in the *Layer 1* for Aluminium liner configured on AS4/Epoxy, while the next Titanium liner configured on AS4/Epoxy, followed by PEEK liner configured on AS4/PEEK, respectively. In the same vein as observed in Fig. 11 [b(i), b(ii), b(iii)] for the transverse direction for the three cases, the S.F limit value of 1.0, 1.0 and 1.0 were recorded in the *Layer 21* for Aluminium liner configured on AS4/Epoxy, followed by Titanium liner configured on AS4/Epoxy and PEEK liner configured on AS4/PEEK, respectively. Thus, it can be opined that the transverse direction had the most critical stresses and can be used to evaluate the minimum wall thickness of the structure. The other loadings for the tension, collapse and tension with external pressure are also presented in Figs. 12–13 for the same configuration but two combinations of the materials, namely the PEEK liner configured on AS4/PEEK and the Aluminium liner configured on AS4/Epoxy. It was observed that they had similar behaviours but the former generally had more stress magnitudes than that of the later.

4.1.2. *Result of local design*

For the local design, the stack-sequence and fibre thicknesses in Table 8 to obtain the results presented in Figs. 14and15. Based on the

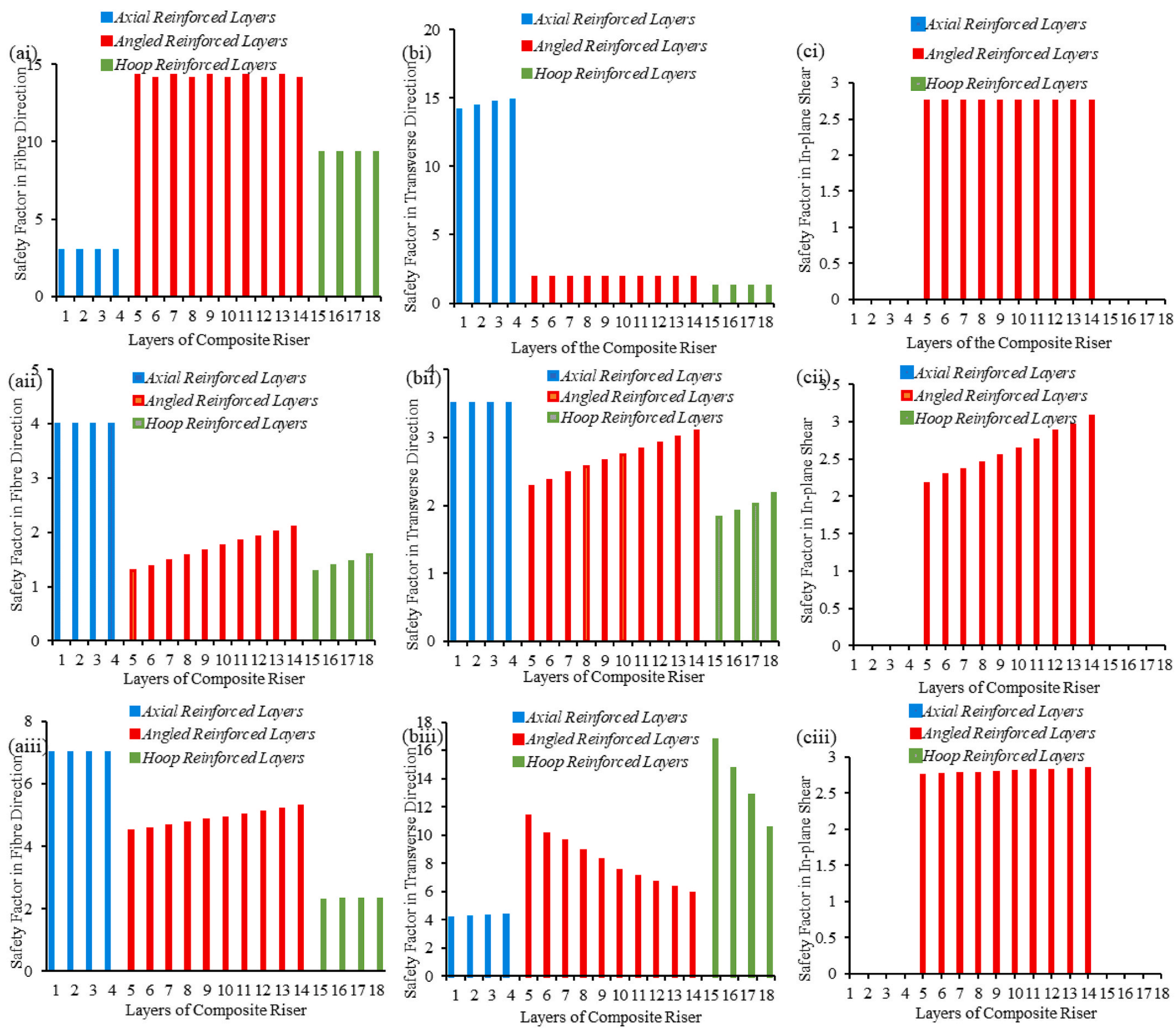

Fig. 15. Safety Factor distribution on: i) pure tension loadings along (ai) Fibre, (bi) Transverse and (ci) In-plane Shear Directions. ii) burst loadings along (aii) Fibre, (bii) Transverse and (cii) In-plane Shear Directions; iii) collapse loadings along (aiii) Fibre, (biii) Transverse and (ciii) In-plane Shear Directions, by utilising Aluminium liner combining AS4/Epoxy configured on $[0_4,(\pm 53.5)_5,90_4]$ model.

study, the local design considers the $[0_3,(\pm 53.5)_5,90_4]$ configuration. Fig. 14 presents the burst case results for different material combinations. However, the AS4/Epoxy material of the composite riser was lined with liners to protect external and internal pressure loads, as in Figs. 14 and 15. In this model, the titanium liner has a thickness of 2.0 mm. During the boundary conditions, fixed ends were considered, and the burst case with end impact. At 155.25 MPa pressure value, the burst (or internal pressure) was calculated. However, it was subjected to a lower external pressure of 60 MPa during the collapse (or external pressure). In line with the investigation presented by Amaechi et al. (2019a), this study was carried out to obtain the S.F values, which differ from Utilization Factors (U.F.). A key aspect included in this investigation that focuses on the fibres for the composite tubular structures was the influence of the offshore operation while installing the riser and then exerting tension on its fibre-layers, as shown in Fig. 15(a). The S.F values across the hoop layers and axial layers are infinity for the 3rd stress component path (in-plane shear path) since they are negligible but not entirely valued with zeroes or empty, as depicted in Fig. 15 (ci, cii, ciii). There is higher magnitude in the Safety Factor recorded in the off-axis layers. As a result, increasing tension in the off-axis layers reduces stresses along that path for the 3rd stress component (in-plane shear path). This implies that the installation of composite risers could pose a challenge, so the installations must be aligned in the direction of the fibres to ensure high service life and successful installation, even a hybrid composite riser or a composite production riser.

4.1.3. Result of tailored design

For the tailored design, some configurations were considered. Fig. 16 shows the first model, which was the Aluminium liner onto AS4/Epoxy combination onto, while the second model was Steel liner onto P75/Epoxy combination in Fig. 17. Both cases were investigated with $[\pm 69/69/90_8/\text{-}69/(\pm 69)_2,0_3]$ configuration, with the thickness as presented in Table 9. It can be observed that the tailored design has a unique influence on the stress magnitudes obtained. As such, it is also recommended that the composite riser can be tailored to fit a specific design purpose or environmental condition by considering a tailored design for

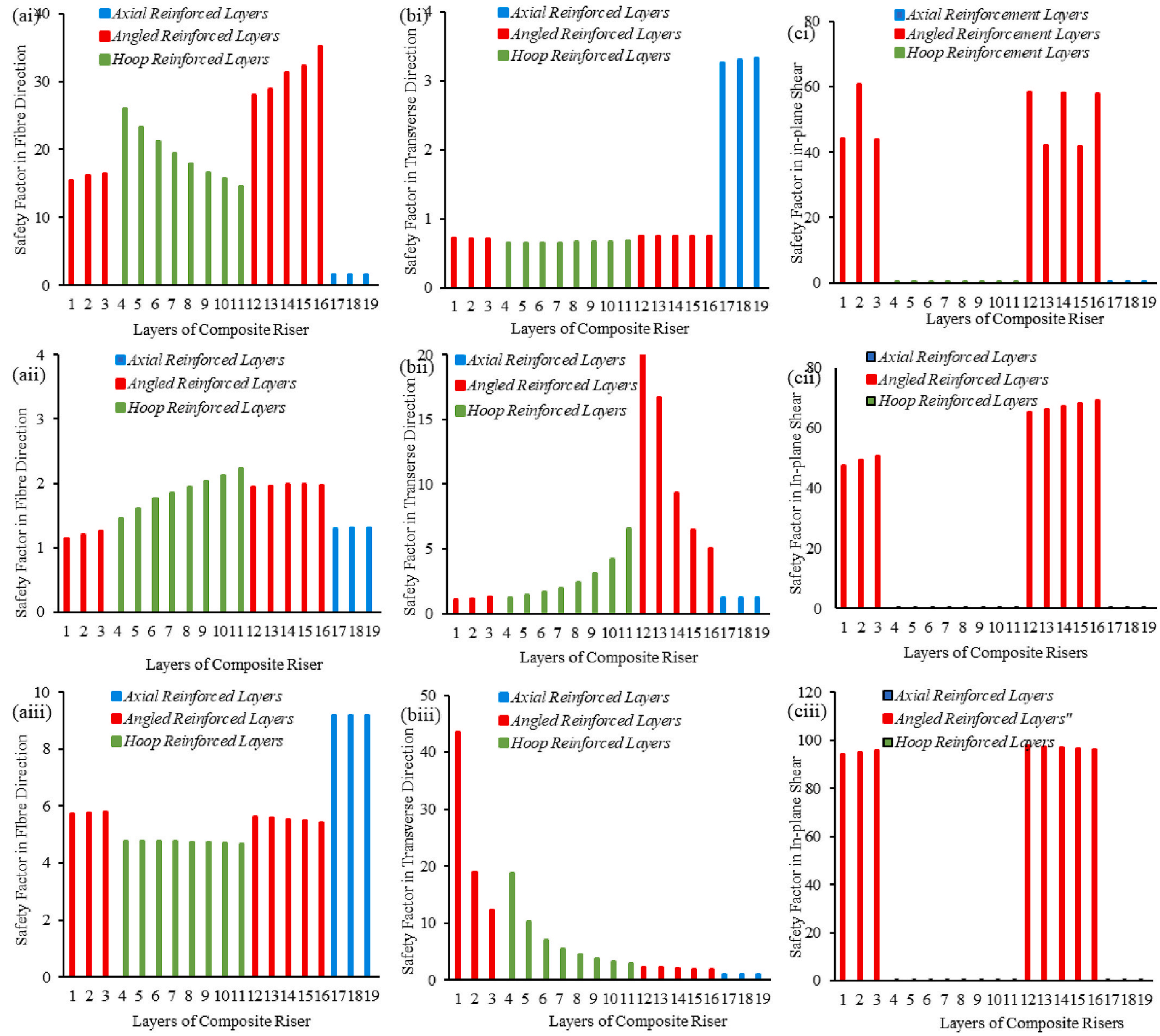

Fig. 16. Safety Factor distribution on: i) pure tension loadings along: (ai) Fibre, (bi) Transverse and (ci) In-plane Shear Directions; ii) burst loadings along: (aii) Fibre, (bii) Transverse and (cii) In-plane Shear Directions; iii) collapse loadings along: (aiii) Fibre, (biii) Transverse and (ciii) In-plane Shear Directions; designed utilising Aluminium liner by combining AS4/Epoxy configured on $[\pm 69/69/90_8,/\text{-}69/(\pm 69)_2,0_3]$ model.

the composite riser. Considering both configurations, the P75/Epoxy and Steel liner performed better as it had comparatively lower factor of safety in comparison to the AS4/Epoxy and aluminium liner.

4.2. Parametric studies

4.2.1. Effect of reinforcement fibres by axial angle

From the parametric studies on the effect of reinforcement fibres by the axial angle, different fibre orientations of the hoop angle were analysed on the layers of riser. It was applied via Aluminium liner combining AS4/Epoxy configured on $[(0)_4,(\pm 53.5)_5,(90)_4]$ model configuration. This is depicted in the profile in Fig. 18(a–f). It can be observed that these models performed closely. Three cases were compared for the 0° hoop angle; these are the Fibre Axial 0, Fibre Axial 0 to 0.5, and Fibre Axial 0 to 1. It can be observed that a decrease in the axial angle of the fibre led to an increase in the stress profile along the different stress components, as depicted in Fig. 18. Thus, the closer the angle to the hoop angle of 0°, the lesser the stress, however the values had very close proximity, as investigated.

4.2.2. Effect of reinforcement fibres by hoop angle

From the parametric studies on the effect of reinforcement fibres by the hoop angle, different fibre orientations of the hoop angle, were presented in Fig. 19(a–f). It was analysed on the layers of riser applied via Aluminium liner combining AS4/Epoxy configured on $[(0)_4,(\pm 53.5)_5,(90)_4]$ model configuration. It can be observed that the performed closely when subjected to internal pressure. Three cases were compared for the 90° hoop angle; these are the Fibre Hoop 90, Fibre Hoop 90 to 89.5, and Fibre Hoop 90 to 89. As shown in Fig. 19(a–f), the model studied were configured with different number of layers and changes on the hoop angles. These are the following models: $[(0)_4,(\pm 53.5)_5,(89)_4]$, $[(0)_4,(\pm 53.5)_5,(89.5)_4]$ and $[(0)_4,(\pm 53.5)_5,(90)_4]$. It is evident that a reduction in the angles for the hoop layers led to an increase in the stress profile along the stress components. Thus, it is

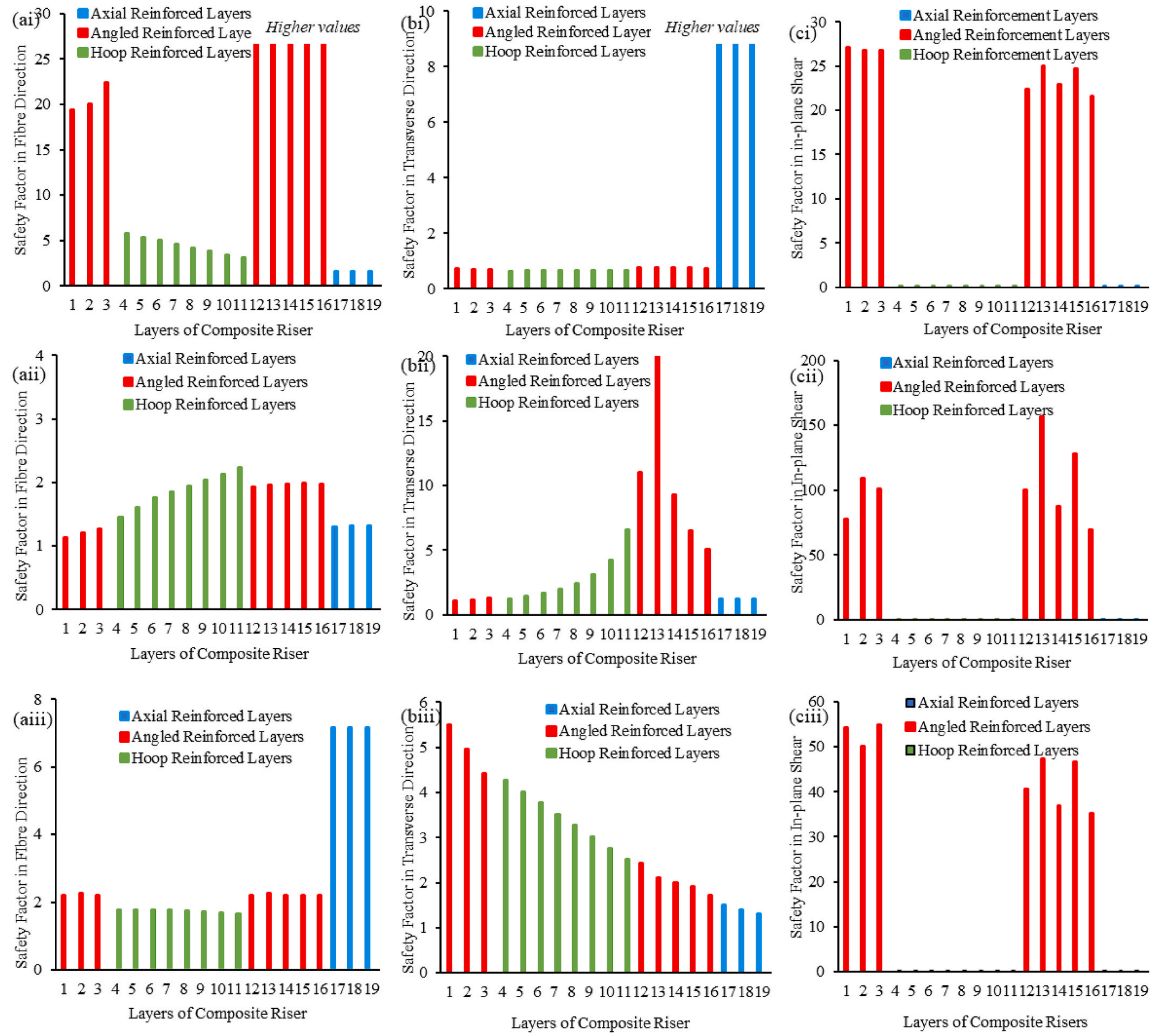

Fig. 17. Safety Factor distribution on: i) pure tension loadings along: (ai) Fibre, (bi) Transverse and (ci) In-plane Shear Directions; ii) burst loadings along: (aii) Fibre, (bii) Transverse and (cii) In-plane Shear Directions; iii) collapse loadings along: (aiii) Fibre, (biii) Transverse and (ciii) In-plane Shear Directions; designed by utilising Steel liner combining P75/Epoxy configured on $[\pm69/69/90_8,/-69/(\pm69)_2,0_3]$ model.

observed that closer angles to the hoop angle of 90° lessens the stress, however the values had very close proximity, as investigated.

4.2.3. *Effect of orientations by amount of layers*

From the parametric studies on the effect of different orientations by the amount of plies, various models were developed and investigated. Six unique models were investigated subjected to burst loadings, similar to the representation in Fig. 15(aii, bii, cii). These six unique models were used to generate the result profiles in Fig. 20(a–i). The configurations for the models are: $[0_4,(\pm53.5)_3,90_3]$, $[0_3,(\pm53.5)_5,90_3]$, $[0_3,(\pm53.5)_5,90_4]$, $[0_4,(\pm53.5)_4,90_4]$, $[0_3,(\pm53.5)_4,90_4]$ and $[0_4,(\pm53.5)_5,90_3]$. A comparison was carried out on these against a base case model configured as $[0_4,(\pm53.5)_5,90_4]$ which is presented in the local design on Fig. 14(a–c). It is evident that the performance of this model configuration was the most effective model. It can be concluded that increasing the amount of plies decreases the stress magnitude on the plies. Details on this has been presented in earlier investigation by author (Amaechi et al., 2019a).

4.2.4. *Effect of liner in load bearing*

Using the model configured as $[0_4,(\pm53)_5,90_4]$ for AS4/Epoxy combination for the composite riser, the investigation on the influence of liners in load bearing was carried out, using the liner model by the author in literature (Amaechi et al., 2019a). A variety of liners as presented in Table 4 were considered, which include the following: PEEK, Titanium, PVDF, PA12, Aluminum and steel liners. The stress profiles were obtained on the different loadings. By utilising the same configuration, it was observed that the least magnitude recorded was on PA12, indicating it had the weakest power in withstanding loads. The implication is that innovative concepts that can be effective in composite riser development can be invented. This will perform well when developed or made with PA12. However, when compared to the liners that have isotropic properties like steel, aluminium and titanium, it was the least performing liner material which considerably displays strong liner

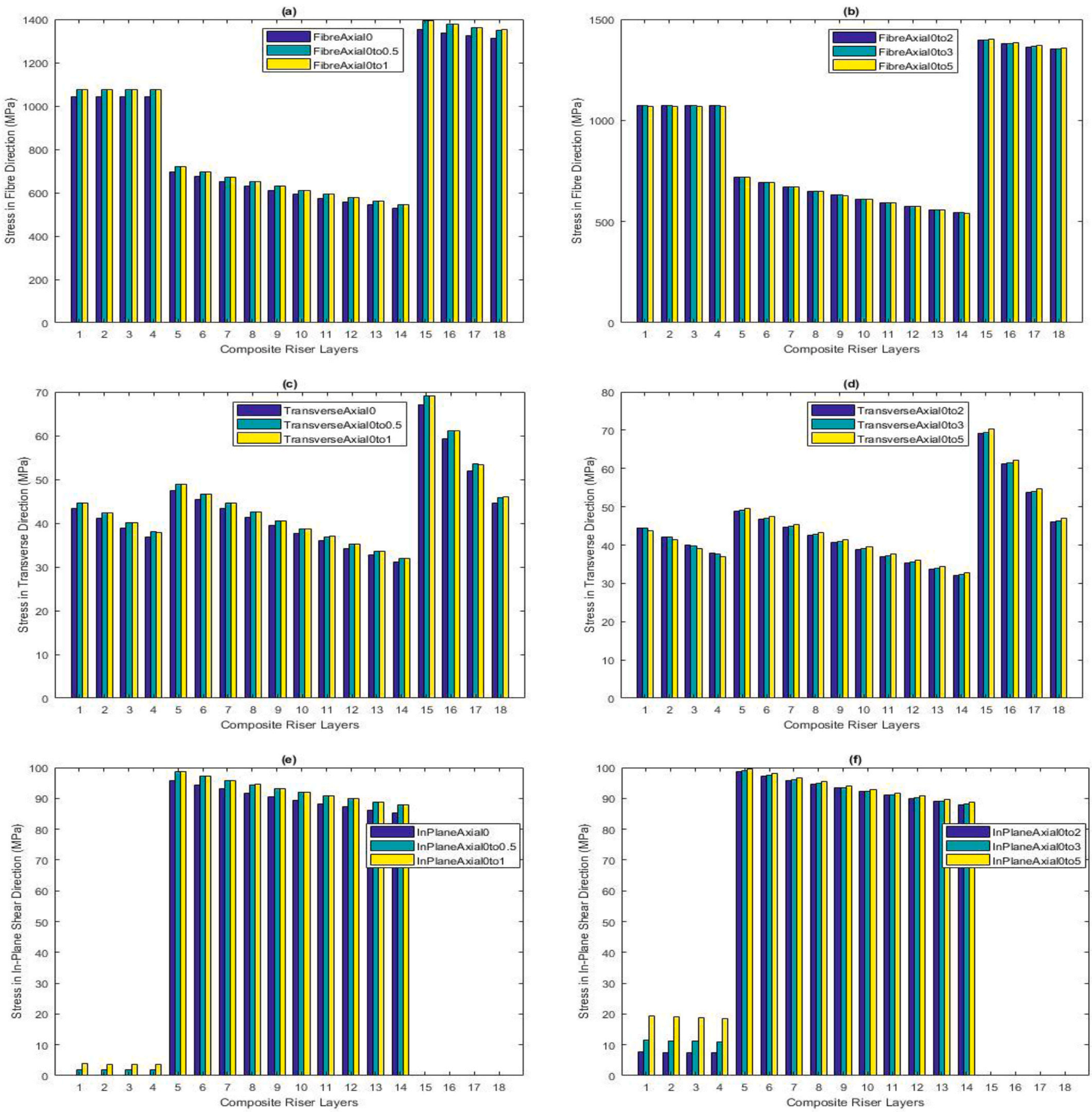

Fig. 18. Stress distribution along: i) the fibre (a, b); ii) the transverse (c, d) and iii) the in-plane Shear (e, f) Directions configured as $[0_4,(\pm 53.5)_5,90_4]$ investigating the influence of the orientation of the axial layer by utilising the Aluminium liner combining AS4/Epoxy.

composition for application on marine composites. Steel liners outperformed titanium liners. Both the PEEK and PVDF liners had approximately similar magnitudes of 1124.39 MPa for the plies in the fibre path (that is 90° angle). Titanium liners were also considered, as seen in Section 4.2.5; however, the high cost of the material prevents its widespread use on composite risers, and thus possess a challenge on its applicability.

4.2.5. *Result of CPR buckling*

Buckling analysis was conducted on six (6) composite riser liner designs as presented in Table 10. It shows the buckling pressure and the number of circumferential waves and half waves. Details of the mode shapes are given in Figs. 21–27. Different modes of the buckling analysis performed on the CPR design are shown in the buckling profiles. It is noteworthy to add that these profiles are not real displacement but buckling modes that indicate the trend of deformation at the critical pressure. They are both normalised and relative values. Thus, the related stresses are not the real stress and have no use in design but indicative. This buckling method has been verified in earlier studies on composite pipe buckling (Amaechi et al., 2019a; Gillett, 2018; Ye and Soldatos, 1995; Ye, 2003). In the linear buckling analysis, the load applied was an external pressure of 60 MPa. Figs. 21–27 represent the plan and end views of various mode forms for modes 1–4. For the CPR design, Mode 1 has the most critical buckling effect, as confirmed in earlier studies

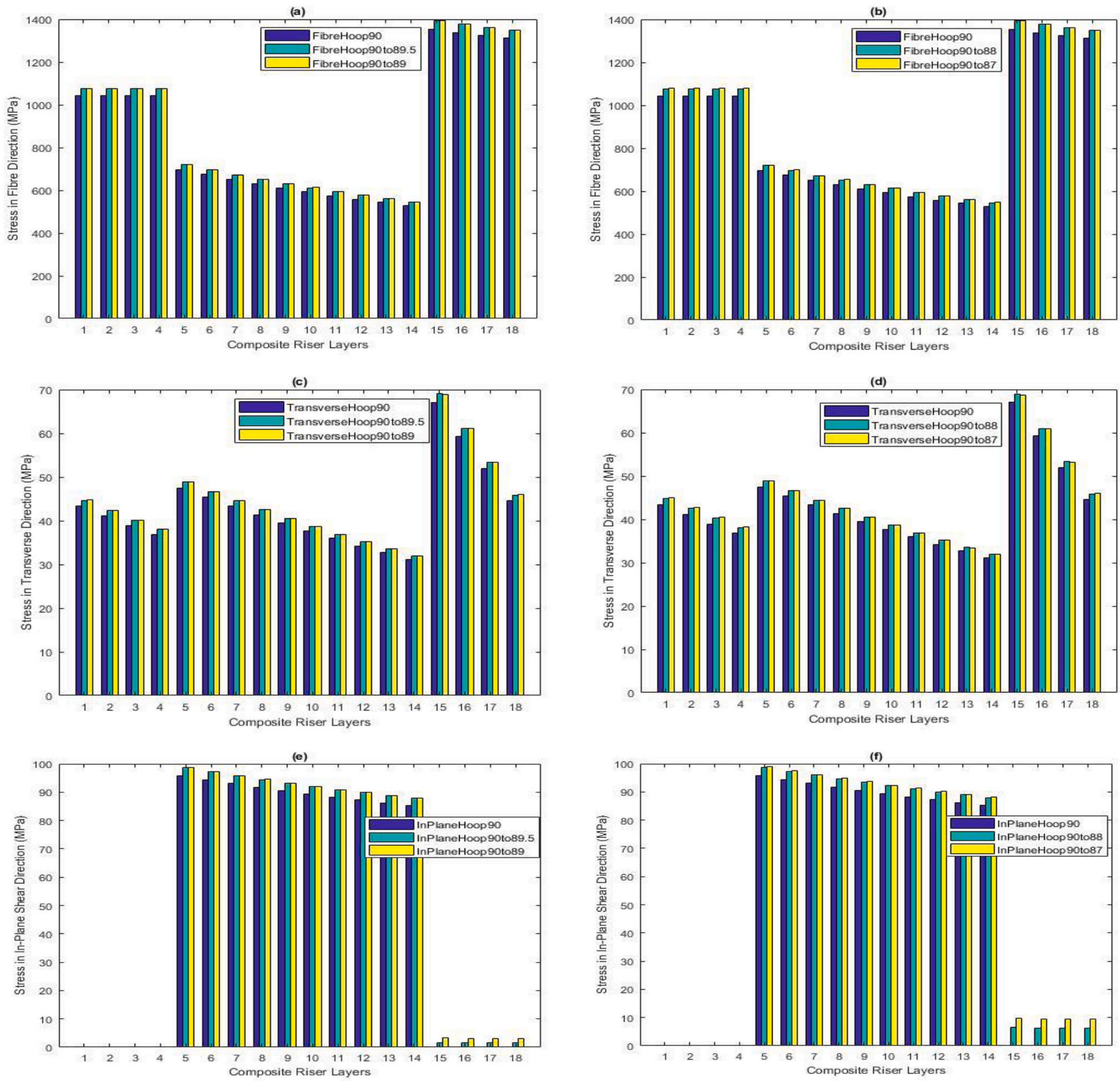

Fig. 19. Stress distribution along: i) the fibre (a, b); ii) the transverse (c, d) and iii) the In-plane Shear (e, f) Directions configured as $[0_4,(\pm 53.5)_5,90_4]$ investigating the influence of the orientation of the hoop layer by utilising the Aluminium liner combining AS4/Epoxy.

(Amaechi et al., 2019a, Gillett, 2018). The maximal deformations, circumferential waves and axial waves obtained are shown in Table 10. According to the findings, the critical buckling pressure was highest in the first model of composite riser with steel liner. However, as the mode shape increased, the buckling pressure increased thus leading to an increase of over 50%. The next mode that was influenced is the AS4/PEEK composite riser having the critical buckling pressures for Modes 1 and 2 as 75.6 MPa, which is around 30% greater than the design buckling value of 60 MPa. The mode shapes are depicted with a relative scale factor for visualisation rather than in true scale of the deformation. In this buckling investigation, the CF T700/Epoxy had the least buckling pressure of 61.33 MPa in Modes 1 and 2. However, the postprocessing on the buckling analysis is not conducted but recommended to check the design limits. Also, it will help in accessing the utilization factors (U.F) to ascertain the limits for the full-scale design of the composite riser.

5. Conclusion

The tailored local design on the composite production riser was presented for deep water applications. This CPR model was developed by using the material properties given in Section 3.1. Three design approaches were utilised: traditional (or conventional), local, and customised (or tailored) design methodologies. Different configurations were considered in this analysis, and the structure is made up of configurations of 18 layers, 19 layers and 21 layers. The design varieties of the composite riser model were successfully developed. The stresses on the composite riser wall were determined using five design loadings. The customised local design was numerically investigated for the multi-layered composite riser model. In general, the design method for this composite riser model demonstrated a 'safe design procedure' by taking maximum stress limit failure requirements into account. The Safety

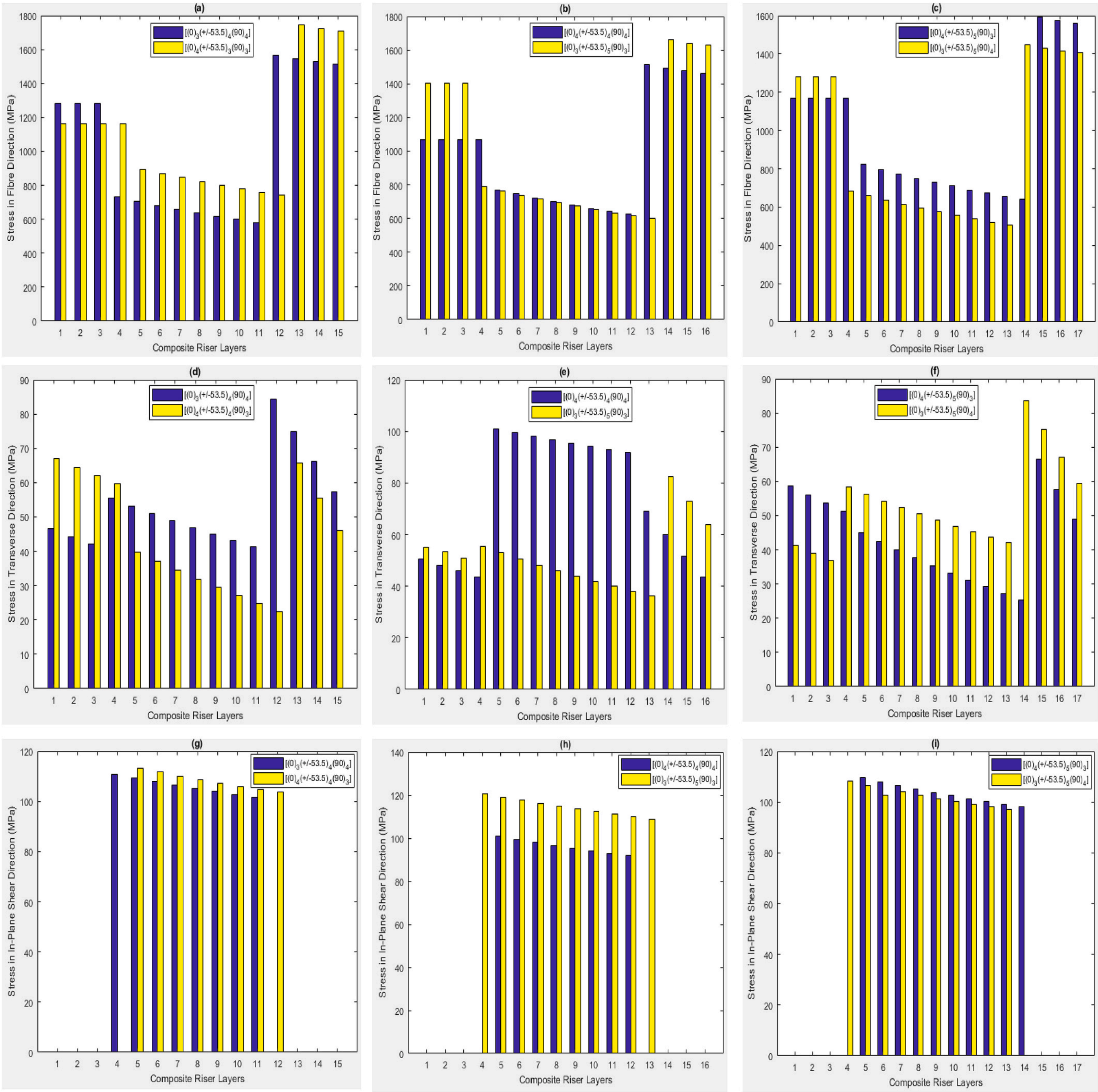

Fig. 20. Stress distribution along: i) fibre (a, b, c); ii) transverse (d, e, f); iii) In-plane Shear Directions (g, h, i), configured utilising [0_4,($\pm$53.5)$_3$,90_3], [0_3,($\pm$53.5)$_5$,90_3], [0_3,($\pm$53.5)$_5$,90_4], [0_4,($\pm$53.5)$_4$,90_4], [0_3,($\pm$53.5)$_4$,90_4], [0_4,($\pm$53.5)$_5$,90_3], investigating the influence from amount of plies by applying Aluminium liner combining AS4/Epoxy (Reproduced, with permission of Elsevier Publishers; Courtesy: Amaechi et al., 2019a).

Factor obtained on the composite riser plies can aid manufacturers and researchers of composite riser pipes as well as other composite marine structures. There is a lot of work that the industry needs to do relative to composite risers. This paper certainly is helpful as it provides some level of help in that regard.

However, it should be noted that this is a nonlinear dynamics problem (not because the pipe is composite but because of large displacement/large rotations) and strength and fatigue have to be addressed in a rigorous manner.

In this study, the model highlights include the following: firstly, composites were used to improve the material behaviour of the composite marine risers by optimized layer from netting theory. Secondly, three design methodologies-conventional, local and tailored designs were considered using the factor of safety on stress investigations. Thirdly, some novelty in the material modelling for the FEM of composite risers, used for the local design in ANSYS ACP and ANSYS Structural for different material configurations. This model can also be used as input properties in analytical models and validation of similar models. Fourthly, the study includes a comparative study of composite riser designs with the mechanical characterization of the deep water composite riser. Lastly, the parameters in the FEA of the composite structure were applied in the parametric investigation.

From this study, the following conclusions and recommendations were made:

Table 10
Results of Eigen Buckling Analysis for composite riser.

Mode		1	2	3	4
Amount of Circumferential Waves		2	2	2	2
Amount of Axial Half-Waves		1	1	2	2
Material					
Steel	Buckling Pressure (MPa)	73.31	73.31	104.50	104.50
	Max Deformation	0.082314	0.082861	0.046419	0.044839
AS4/PEEK	Buckling Pressure (MPa)	75.6	75.6	76.8	76.8
	Max Deformation	1.00	1.33	1.00	1.25
AS4/Epoxy	Buckling Pressure (MPa)	61.88	61.88	64.91	64.91
	Max Deformation	0.082448	0.083047	0.083084	0.082433
CF T700 Epoxy	Buckling Pressure (MPa)	61.33	61.33	62.40	62.40
	Max Deformation	0.082966	0.08223	0.046435	0.044929
GF S-2 Epoxy	Max Deformation	0.082918	0.082185	0.046873	0.044408
	Amount of Circumferential Waves	2	2	2	2
IM7/PEEK	Buckling Pressure (MPa)	62.23	62.23	61.11	61.11
	Max Deformation	0.0831	0.082777	0.044075	0.048433
P75/PEEK	Buckling Pressure (MPa)	62.58	62.58	65.42	65.42
	Max Deformation	0.082421	0.083056	0.082944	0.082526

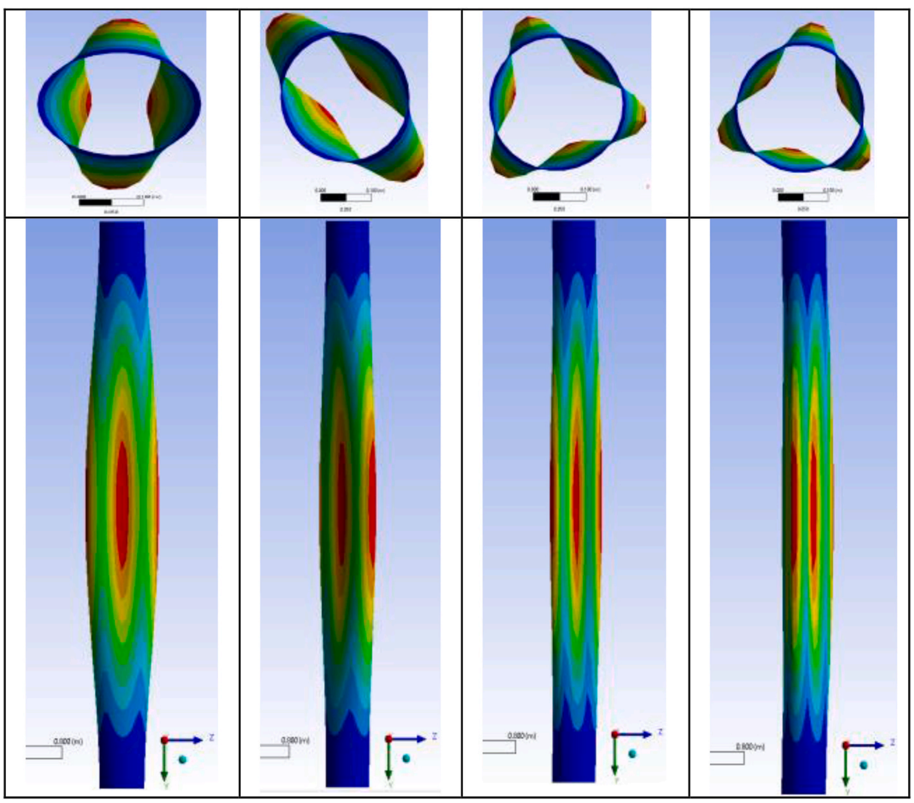

Fig. 21. Steel liner's Eigen Buckling of mode shape of plan and end views of modes 1–4 deformation in ANSYS R2020.

1. There has been a successful presentation of the three design approaches on the composite riser. The internal pressure loading was deemed the most critical in this investigation because it caused the most stress on the layers. As a result, it was crucial in determining the design configuration and the structural efficiency of composite risers. More stress distributions were observed in the hoop layers along the fibre direction. The recorded stress impacts are caused by component forces operating across each lamina. Also, the application of conventional designs showed that the tailored designs are better for CPRs.
2. From the parametric study, different parameters were investigated to obtain the best design and material combination. The choice was made from the numerical analysis of the various stress profiles. This investigation showed that some responses to the load effects were taken in and absorbed by the liner during the internal pressure loadings. It showed to perform well, although, further research is required on the optimization of the external (or outer) liners since it would not help to increase the inner liner reinforcement further inwards.
3. From the design using the liner model for CPR in Amaechi et al. (2019a), liners have been observed as load-bearing, and different liner combinations were carried out. It is recommended to consider liners like PA12 and to include environmental loads from global design of the CPR. In addition, the PEEK liner under the AS4 PEEK combination had good performance, thus it is recommended on this design. This study reflects the behaviour of CPRs with the liners, but since the design reflects to be response-sensitive and

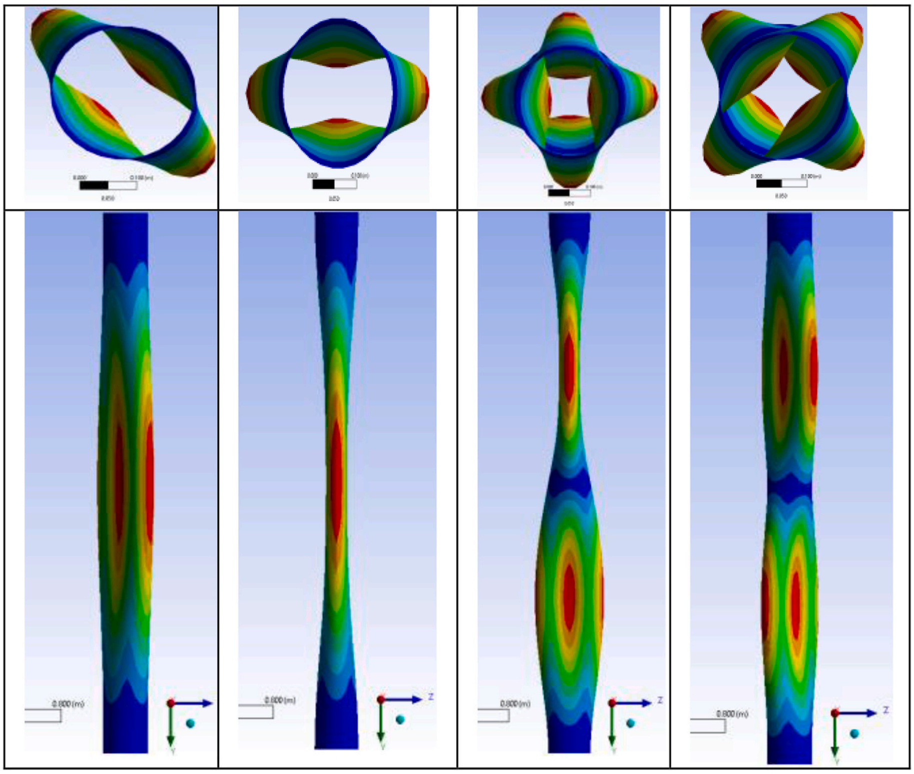

Fig. 22. AS4/PEEK liner's Eigen Buckling of mode shape of plan and end views of modes 1–4 deformation in ANSYS R2020.

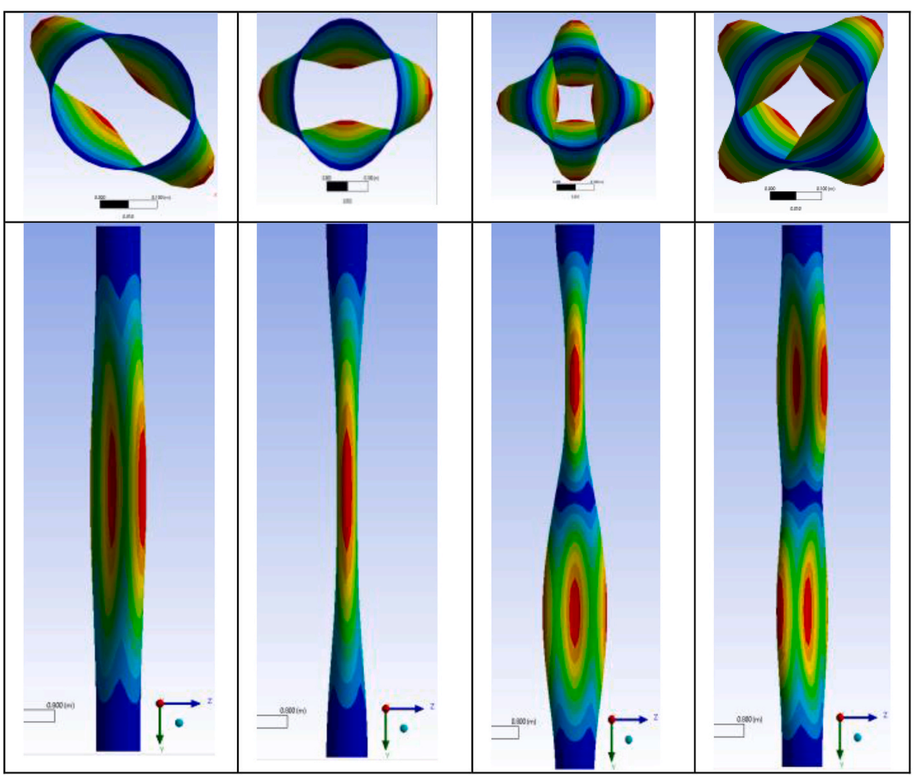

Fig. 23. AS4/Epoxy liner's Eigen Buckling of mode shape of plan and end views of modes 1–4 deformation in ANSYS R2020.

fatigue-sensitive, the global dynamic analysis of full-length composite riser is recommended.

4. For the design and analysis of composite risers, this method is advantageous. Stress assessments of composite cylinders with numerous layers of different fibre angles or materials can be performed efficiently using this method because there is ease in modelling, as well as coupling the local and global design. With this

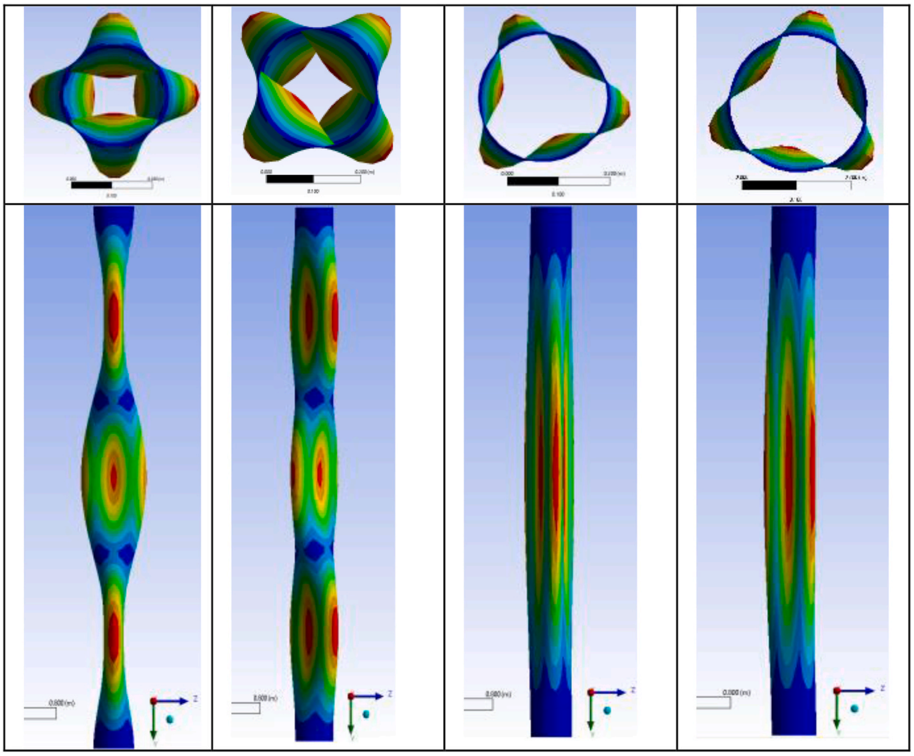

Fig. 24. Carbon fibre T700 Eigen Buckling of mode shape of plan and end views of modes 1–4 deformation in ANSYS R2020.

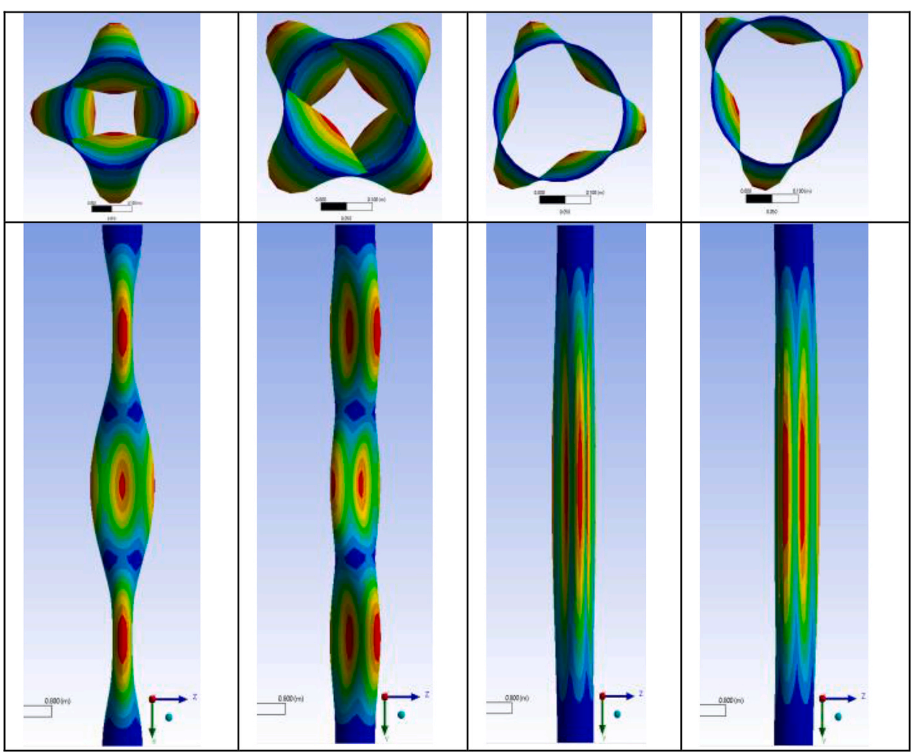

Fig. 25. Glass fibre S-2 Eigen Buckling of mode shape of plan and end views of modes 1–4 deformation in ANSYS R2020.

method, the interfacial stresses can also be obtained to predict the CPR behaviour.

5. From the tailored design, it can be observed that the angles of the composite risers can be inclined to produce a different behaviour. As such, it is recommended to investigate the behaviour of the tailored design under environmental loadings. However, this should be compared with the optimized composite riser from the local design, as it will have high performance capacity, be very load bearing with high strength and able to withstand extreme environmental conditions. Local design of CPR was presented in this study but detailed

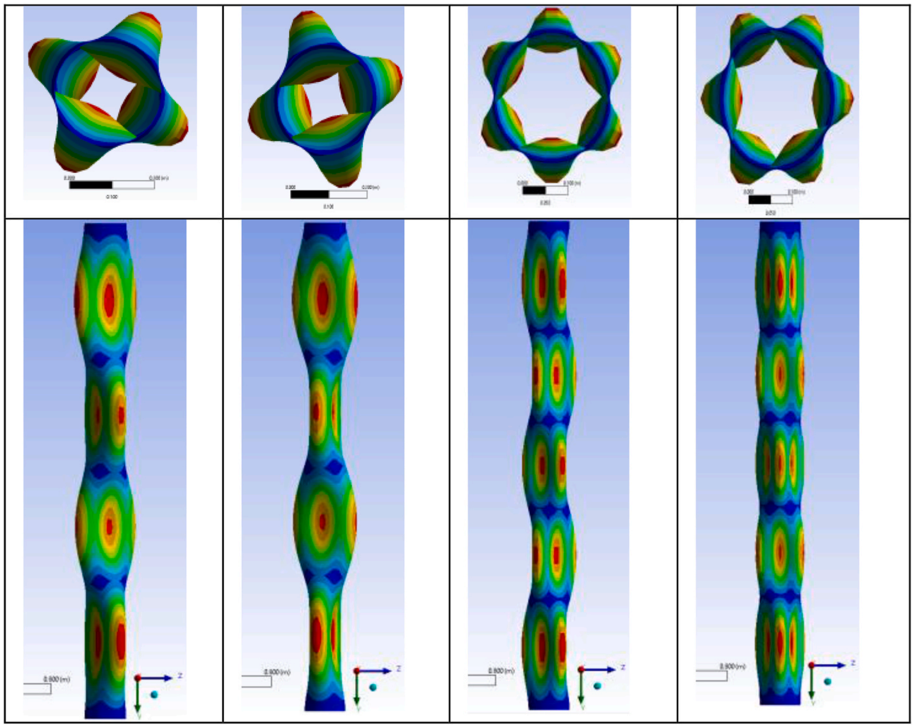

Fig. 26. IM7/PEEK Eigen Buckling of mode shape of plan and end views of modes 1–4 deformation in ANSYS R2020.

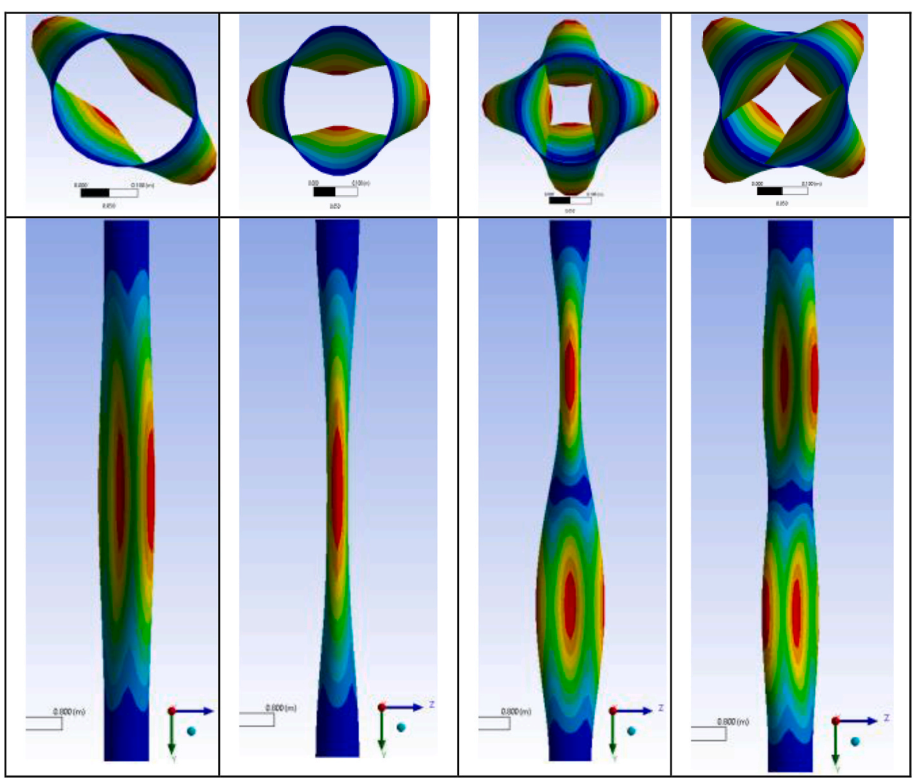

Fig. 27. P75/PEEK liner's Eigen Buckling of mode shape of plan and end views of modes 1–4 deformation in ANSYS R2020.

composite riser fatigue, vortex-induced effect of the composite riser and the operational envelope is recommended for future research.

Data availability statement

The raw/processed data required to reproduce these findings cannot be shared at this time as the data also forms part of an ongoing study.

Funding

The Department of Engineering, Lancaster University, UK and EPSRC Doctoral Training Center (DTC) are highly appreciated. Also, the funding support from Niger Delta Development Commission (NDDC), Nigeria (under the platform of Overseas Postgraduate Scholarship backed by Abia State Government), and the support of Standards Organisation of Nigeria (SON), Abuja, Nigeria are well appreciated.

CRediT authorship contribution statement

Chiemela Victor Amaechi: Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Resources, Data curation, Writing – original draft, Writing – review & editing, Visualization, Supervision, Project administration, Funding acquisition.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgement

The authors acknowledge the technical support from Andy Baker of Lancaster University Engineering Department for necessary technical permissions to use high performance PCs in the Engineering Lab, and the support of Andy Gavriluk for support with computational resources. We acknowledge the project contributions of my Lancaster University research group, for contribution to the earliest development of the ANSYS composite riser model. In addition, technical support from Nathaniel Gillet of Trident Energy, UK and Dr. Wang Chunguang of Shandong University China during the validation of the composite riser model are acknowledged. Also, recognise Dr. Stephen Hatton of Magma Global for assistance with providing Fig. 1 and granting permission to use it in this study. The authors acknowledge Offshore Technology Research Center (OTRC), USA for providing composite riser reports. Thanks to both Abiodun K. Oyetunji of Lancaster University, UK and Mpho Kgosiemang of UCLAN, UK for reviewing this manuscript. Also acknowledge the permission of Elsevier to reuse my image in Fig. 20. The ANSYS′ support team is appreciated for technical support in modelling the riser in this research. Lastly, the authors appreciate the detailed feedback from the reviewers and editors on this manuscript.

Abbreviations list

υ_1, υ_2, υ_3	Poisons Ratio
θ	Angle for fibre or ply angle
ρ_f	density of the fibres
ρ_m	density of the matrix
E_f	stiffness of the fibres
E_m	stiffness of the matrix
V_f	volume fraction of the fibres
V_m	volume fraction of the matrix
3D	Three-Dimensional
3DoF	three degrees of freedom
ABS	American Bureau of Shipping
ATP	Advanced Technology Programs
CAD	computer aided design
CF	Carbon fiber
CMR	Composite Marine Riser
CPR	Composite Production Riser
DOE	Design of Experiments
E_1, E_2, E_3	Elastic Modulus
FEA	Finite Element Analysis
FEM	Finite Element Model
FRP	Fibre Reinforced Polymer
FVF	Fibre volume fraction
G_{12}, G_{13}, G_{23}	Shear Modulus
GF	Glass fiber
HDPE	High Density Poly Ethelene
HM	High Modulus
HS	High Strength
IFP	Institut Francais du Petrole
LC	Load Case
NIST	National Institute of Standards and Technology
PA12	Polyamide 12
PEEK	Poly Ether Ether Ketone
PSD	Power Spectral Density
PVDF	Polyvinylidene fluoride
RMS	Root Mean Square
ROM	Rule of Mixture
S.F	Safety Factor
S-2	AGY glass fibre
SAEA	Surrogate-Assisted Evolutionary Algorithm
SCR	Steel Catenary Risers
SON	Standards Organisation of Nigeria
T700	Toray carbon fibre
TCP	Thermoplastic Composite Pipes
TLP	Tension Leg Platform
TTR	Top Tensioned Riser
UD	Unidirectional
U.F	Utilization Factors
VIV	Vortex Induced Vibration

References

ABS, 2017. Guide for Building and Classing Subsea Riser Systems, third ed. American Bureau of Shipping, New York, USA. Available at: https://ww2.eagle.org/content/dam/eagle/rules-and-guides/current/offshore/123_guide_building_and_classing_subsea_riser_systems_2017/Riser_Guide_e-Mar18.pdf. 16th May, 2021.

Ahlstone A.G. (1973). Light weight marine riser pipe. US3768842 Patent, USA. Available at: https://www.freepatentsonline.com/3768842.pdf and https://patentimages.storage.googleapis.com/a4/08/e6/0a054a58e51d97/US3768842.pdf (Accessed April 12, 2021).

Akula, V.M.K., 2014. Global-local analysis of a composite riser. Paper number: PVP2014-28054. Design and Analysis. In: Proceedings of the ASME 2014 Pressure Vessels and Piping Conference, vol. 3. ASME, Anaheim, California, USA, pp. 1–9. https://doi.org/10.1115/PVP2014-28054. July 20–24, 2014. V003T03A010.

Alexander, C., Vyvial, B., Cedergery, C., Baldwin, D., 2013. Evaluating the performance of a composite-reinforced steel drilling riser via full-scale testing for HPTH service. Paper IOPF2011-4002. In: Proceedings of the 6th International Offshore Pipeline Forum IOPF 2011. October 19-20, 2011, Houston, Texas, USA. Available at: https://www.chrisalexander.com/wp-content/uploads/2020/05/4-1.pdf.

Alexander, C., 2011. Assessing the Use of Composite Materials in Reinforcing Offshore Risers and Pipelines. In: Proceedings of the ASME 2011 30th International Conference on Ocean, Offshore and Arctic Engineering, Volume 4. Pipeline and Riser Technology, Rotterdam, The Netherlands, pp. 381–390. https://doi.org/10.1115/OMAE2011-49425. June 19–24, ASME.

Altenbach, H., Altenbach, J., Kissing, W., 2004. Mechanics of Composite Structural Elements, 1st Ed. Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-662-08589-9.

Amaechi, C.V., 2022. Novel Design, Hydrodynamics and Mechanics of Marine Hoses in Oil/gas Applications. PhD Thesis. Engineering Department, Lancaster University, UK (in view).

Amaechi, C.V., Ye, J., 2017. A numerical modeling approach to composite risers for deep waters. In: International Conference on Composite Structures (ICCS20) Proceedings. Societa Editrice Esculapo, Paris, France.

Amaechi, C.V., Ye, J., 2021. A review of state-of-the-art and meta-science analysis on composite risers for deep seas. Ocean Eng. 2021 submitted for publication.

Amaechi, C.V., Ye, J., 2022. An investigation on the vortex effect of a CALM buoy under water waves using Computational Fluid Dynamics (CFD). Inventions 7 (1), 23. https://doi.org/10.3390/inventions7010023.

Amaechi, C.V., Gillett, N., Odijie, A.C., Hou, X., Ye, J., 2019a. Composite risers for deep waters using a numerical modelling approach. Compos. Struct. 210, 486–499. https://doi.org/10.1016/j.compstruct.2018.11.057, 2019.

Amaechi, C.V., Gillett, N., Odijie, A.C., Wang, F., Hou, X., Ye, J., 2019b. Local and global design of composite risers on truss SPAR platform in deep waters. Paper 20005. In: Proceedings of 5th International Conference on Mechanics of Composites, pp. 1–3, 2019, no. 20005.

Amaechi, C.V., Odijie, C., Sotayo, A., Wang, F., Hou, X., Ye, J., 2019c. Recycling of renewable composite materials in the offshore industry. Encycl. Renew. Sustain.

Mater. Ref. Modul. Mater. Sci. Mater. Eng. https://doi.org/10.1016/B978-0-12-803581-8.11445-6.

Amaechi, C.V., Odijie, C., Etim, O., Ye, J., 2019d. Economic aspects of fiber reinforced polymer composite recycling. Encycl. Renew. Sustain. Mater. Ref. Modul. Mater. Sci. Mater. Eng. https://doi.org/10.1016/B978-0-12-803581-8.10738-6.

Amaechi, C.V., Wang, F., Hou, X., Ye, J., 2019e. Strength of submarine hoses in Chinese-lantern configuration from hydrodynamic loads on CALM buoy. Ocean Eng. 171 (2019), 429–442. https://doi.org/10.1016/j.oceaneng.2018.11.010.

Amaechi, C.V., Ye, J., Hou, X., Wang, F.-C., 2019f. Sensitivity studies on offshore submarine hoses on CALM buoy with comparisons for Chinese-lantern and lazy-S configuration OMAE2019-96755. In: 38th International Conference on Ocean, Offshore and Arctic Engineering. Glasgow, Scotland, June 9–14, 2019. Available at: https://eprints.lancs.ac.uk/id/eprint/134404/, 17th November, 2021.

Amaechi, C.V., Chesterton, C., Butler, H.O., Wang, F., Ye, J., 2021a. Review on the design and mechanics of bonded marine hoses for Catenary Anchor Leg Mooring (CALM) buoys, 2021 Ocean. Eng. 242 (7), 1–32. https://doi.org/10.1016/j.oceaneng.2021.110062, 110062.

Amaechi, C.V., Wang, F., Ye, J., 2021b. Mathematical modelling of marine bonded hoses for single point mooring (SPM) systems, with catenary anchor leg mooring (CALM) buoy application—a review, 2021 J. Mar. Sci. Eng. 9 (11), 1–62. https://doi.org/10.3390/jmse9111179, 1179.

Amaechi, C.V., Chesterton, C., Butler, H.O., Wang, F., Ye, J., 2021c. An overview on bonded marine hoses for sustainable fluid transfer and (Un)Loading operations via floating offshore structures (FOS). J. Mar. Sci. Eng. 9 (11), 1236. https://doi.org/10.3390/jmse9111236, 2021.

Amaechi, C.V., Wang, F., Ye, J., 2021d. Numerical assessment on the dynamic behaviour of submarine hoses attached to CALM buoy configured as lazy-S under water waves. J. Mar. Sci. Eng. 9 (1130), 1–48. https://doi.org/10.3390/jmse9101130, 2021.

Amaechi, C.V., Wang, F., Ye, J., 2021e. Understanding the fluid-structure interaction from wave diffraction forces on CALM buoys: numerical and analytical solutions. Ships Offshore Struct. 2021 https://doi.org/10.1080/17445302.2021.2005361.

Amaechi, C.V., Wang, F., Ye, J., 2021f. Numerical studies on CALM buoy motion responses and the effect of buoy geometry cum skirt dimensions with its hydrodynamic waves-current interactions. Ocean. Eng Volume 244 (7), 110378. https://doi.org/10.1016/j.oceaneng.2021.110378, 15 January 2022.

Amaechi, C.V., Adelusi, I., Adefuye, E.F., Oyetunji, A.K., Jae'e, I.A., Wang, F., Ye, J., 2021g. Numerical Study on Plastic Strain Distributions and Mechanical Behaviour of a Tube under Bending. Inventions 2022 7 (1), 9. https://doi.org/10.3390/inventions7010009.

Amaechi, C.V., Wang, F., Ja'e, I.A., Aboshio, A., Odijie, A.C., Ye, J., 2021h. A literature review on the technologies of bonded hoses for marine applications. *Ships and Offshore Structures*. 2022 https://doi.org/10.1080/17445302.2022.2027682.

Amaechi, C.V., Odijie, C.A., Wang, F., Ye, J., 2021i. Numerical investigation on mooring line configurations of a Paired Column Semisubmersible for its global performance in deep water condition. Ocean Eng 2021. https://doi.org/10.1016/j.oceaneng.2022.110572.

Amaechi, C.V., Wang, F., Ye, J., 2021j. Dynamic analysis of tensioner model applied on global response with marine riser recoil and disconnect. Mar. Struct. 2021 (submitted for publication).

Amaechi, C.V., Wang, F., Ye, J., 2021k. Parametric investigation on tensioner stroke analysis, recoil analysis and disconnect for the marine drilling riser of a Paired Column Semisubmersible under deep water waves. Ocean Eng. 2021 (submitted for publication).

Amaechi, C.V., Wang, F., Ye, J., 2021l. Investigation on hydrodynamic characteristics, wave-current interaction and sensitivity analysis of submarine hoses attached to a CALM buoy. J. Mar. Sci. Eng. 2022 10 (1), 120. https://doi.org/10.3390/jmse10010120.

Amaechi, C.V., Chesterton, C., Butler, H.O., Gillet, N., Wang, C., Ja'e, I.A., Reda, A., Odijie, C.A., 2022a. Review of composite marine risers for deep-water applications: design, development and mechanics. J. Compos. Sci. 6 (3), 96. https://doi.org/10.3390/jcs6030096.

Amaechi, C.V., Chesterton, C., Butler, H.O., Gu, Z., Odijie, C.A., Wang, F., Hou, X., Ye, J., 2022b. Finite element modelling on the mechanical behaviour of Marine Bonded Composite Hose (MBCH) under burst and collapse. J. Mar. Sci. Eng. 10 (2), 151. https://doi.org/10.3390/jmse10020151.

Amaechi, C.V., Chesterton, C., Butler, H.O., Gu, Z., Odijie, C.A., Hou, X., 2022c. Numerical modelling on the local design of a Marine Bonded Composite Hose (MBCH) and its helix reinforcement. J. Compos. Sci. 6 (3), 79. https://doi.org/10.3390/jcs6030079.

Amaechi, C.V., Gillet, N., Ja'e, I.A., Ye, J., 2022d. Tailoring the local design of deep water composite risers to minimise structural weight. J. Compos. Sci. (submitted for publication).

Amaechi, C.V., Wang, F., Ye, J., 2022e. Experimental study on motion characterization of CALM buoy hose system under water waves. J. Mar. Sci. Eng. 10 (2), 204. https://doi.org/10.3390/jmse10020204 (submitted for publication).

Andersen, W.F., Anderson, J.J., Landriault, L.S., 1998. Full-scale testing of prototype composite drilling riser joints-Interim report, OTC 8668. In: Offshore Technology Conference, pp. 147–154. https://doi.org/10.4043/8668-MS. May 4–7, 1998. Houston, USA.

ANSYS, 2017a. *ANSYS Composite PrepPost User's Guide* Release 18.2. ANSYS Inc, USA.

ANSYS, 2017b. ANSYS Meshing User's Guide, Release 18.2. ANSYS Inc, Canonsburg, USA.

Bai, Y., Bai, Q., 2005. Subsea Pipelines and Risers, first ed. Elsevier, Oxford, UK.

Bakaiyan, H., Hosseini, H., Ameri, E., 2009. Analysis of multi-layered filament-wound composite pipes under combined internal pressure and thermomechanical loading with thermal variations. Compos. Struct. 88 (4), 532–541. https://doi.org/10.1016/j.compstruct.2008.05.017. Available at:

Baldwin DD, Reigle JA, Drey MD. Interface System between Composite Tubing and End Fittings. Google Patents; 2000. Available at: https://patents.google.com/patent/WO2004044372A1.

Baldwin, D.D., Johnson, D.B., Composites, L., 2002. Rigid composite risers: design for purpose using performance-based requirements -OTC 14319. In: Offshore Technology Conference - OTC 14319. OnePetro/OTC, Houston, Texas, USA, pp. 1–10. https://doi.org/10.4043/14319-MS.

Baldwin, D.D., et al., 1997. Composite production riser design. In: Offshore Technology Conference -OTC 8431. OnePetro/OTC, Houston, Texas, USA, pp. 1–8. https://doi.org/10.4043/8431-MS.

Baldwin, D.O., Lo, K.H., Long, J.R., 1998. Design verification of a composite production riser. In: Offshore Technology Conference - OTC 8664. OnePetro/OTC, Houston, Texas, USA, pp. 103–112. https://doi.org/10.4043/8664-MS.

Bybee, K., 2003. The first offshore installation of a composite riser joint. Paper number: SPE-0503-0072-JPT. J. Petrol. Technol. 55 (5), 72–74. https://doi.org/10.2118/0503-0072-JPT, 72-72, 2003.

Cai, H., Ye, J.J., Wang, Y.W., Saafi, M., Huang, B., Yang, D.M., Ye, J., 2020. An effective microscale approach for determining the anisotropy of polymer composites reinforced with randomly distributed short fibers. Compos. Struct. 240 (2020) https://doi.org/10.1016/j.compstruct.2020.112087. Article 112087.

Calash, 2015. Commercial Review of 8 Riser SLOR System: Magma M-Pipe versus Steel Pipe, pp. 1–16. Magma Global Report 776.

Cederberg, Chad A., Baldwin, Donald D., Bhalla, Kenneth, Tognarelli, Michael A., 2013. Composite-reinforced steel drilling riser for ultra-deepwater high pressure wells. In: Paper Presented at the Offshore Technology Conference. https://doi.org/10.4043/24150-MS. Houston, Texas, USA, May 2013.

Cederberg, C., 2011. Design and Verification Testing Composite-Reinforced Steel Drilling Riser, Final Report, RPSEA 07121-1401. Lincoln Composites, Inc.

Chen, J., Wan, L., Ismail, Y., 2021a. A micromechanics and machine learning coupled approach for failure prediction of unidirectional CFRP composites under triaxial loading: a preliminary study. Compos. Struct. 267 (July 2021) https://doi.org/10.1016/j.compstruct.2021.113876. Article number 113876.

Chen, J., Wan, L., Ismail, Y., Hou, P., Ye, J., Yang, D., 2021b. Micromechanical analysis of UD CFRP composite lamina under multiaxial loading with different loading paths. Compos. Struct. 269 (August 2021) https://doi.org/10.1016/j.compstruct.2021.114024. Article number 114024.

Chen, Y., Seemann, R., Krause, D., Tay, T.-E., Tan, V.B., 2016. Prototyping and testing of composite riser joints for deepwater application. J. Reinforc. Plast. Compos. 35 (2), 95–110. https://doi.org/10.1177/0731684415607392.

Chesterton, C., 2020. A Global and Local Analysis of Offshore Composite Material Reeling Pipeline Hose, with FPSO Mounted Reel Drum. BEng Dissertation. Engineering Department, Lancaster University, UK.

Dareing, D.W., 2019. Oil well Drilling Engineering. ASME Press, New York, USA. https://doi.org/10.1115/1.861875.

Dareing, D.W., 2012. Mechanics of Drill strings and Marine Risers. ASME Press, New York, USA. https://doi.org/10.1115/1.859995.

DNV, 2002. Titanium Risers: recommended Practice DNV-RP-F201. Det Norske Veritas, Oslo, Norway. Available at: https://rules.dnv.com/docs/pdf/dnvpm/codes/docs/2002-10/RP-F201.pdf (Accessed 16th December 2021).

DNV, 2010a. Composite Risers: recommended Practice DNV-RP-F202 October. Det Norske Veritas, Oslo, Norway. Available at: https://rules.dnv.com/docs/pdf/dnvpm/codes/docs/2010-10/RP-F202.pdf (Accessed 16th December 2021).

DNV, 2010b. Dynamic Risers: offshore Standard DNV-OS-F201, October. Det Norske Veritas, Oslo, Norway. Available at: https://rules.dnv.com/docs/pdf/dnvpm/codes/docs/2010-10/OS-F201.pdf (Accessed 16th December 2021).

DNV, 2013. Composite Components: offshore Standard DNV-OS-C501. Det Norske Veritas, Oslo, Norway. Available at: https://rules.dnv.com/docs/pdf/dnvpm/codes/docs/2013-11/OS-C501.pdf (Accessed 16th December 2021).

DNVGL, 2017a. Modelling and Analysis of Marine Operations. DNVGL-RP-N103. Det Norske Veritas & Germanischer Lloyd, Oslo, Norway.

DNVGL, 2017b. Global Performance Analysis of Deepwater Floating Structures. DNVGL-RP-F205. Det Norske Veritas & Germanischer Lloyd, Oslo, Norway.

DNVGL, 2017c. Offshore Riser Systems: service Specification DNVGL-SE-0476. Available at: https://rules.dnvgl.com/docs/pdf/DNVGL/SE/2017-08/DNVGL-SE-0476.pdf, 8th September, 2021.

DNVGL, 2015. Thermoplastic Composite Pipes: recommended Practice DNVGL-RP-F119. December.. Det Norske Veritas & Germanischer Lloyd, Oslo, Norway. Available at: https://www.dnvgl.com/oilgas/download/dnvgl-st-f119-thermoplastic-composite-pipes.html, 8th September, 2021.

DOD, 2002. Military Handbook, MIL-HDBK-17-3F: composite materials Handbook. In: Polymer Matrix Composites Materials Usage, Design and Analysis, vol. 3. U.S. Department of Defense, USA. Available at: https://www.library.ucdavis.edu/wp-content/uploads/2017/03/HDBK17-3F.pdf, 8th September, 2021.

Drey, M.D., Salama, M.M., Long, J.R., Abdallah, M.G., Wang, S.S., 1997. Composite production riser - testing and qualification. In: Offshore Technology Conference - OTC 8432. OnePetro/OTC, Houston, Texas, USA, pp. 19–27. https://doi.org/10.4043/8432-MS. May 5–8, 1997.

Echtermeyer, A.T., Steuten, B., 2013. Thermoplastic composite riser guidance Note, OTC 24095. In: Offshore Technology Conference, pp. 1–10. https://doi.org/10.4043/24095-MS. Houston, Texas, USA.

Eshiet, K.I.I., 2012. Modelling of Hydraulic Fracturing and its Engineering Application. PhD Thesis. School of Civil Engineering, University of Leeds, Leeds, UK. Available at: https://etheses.whiterose.ac.uk/3148/1/Eshiet_KI_CivilEngineering_PhD_2012.pdf, 8th September, 2021.

Evans, J.T., Gibson, A.G., 2002. Composite angle ply laminates and netting analysis. Proceedings: Math. Phys. Eng. Sci. 458 (2028), 3079–3088. Available at: https://www.jstor.org/stable/3560099, 8th September, 2021.

Fernandes da Silva, R., Teófilo, F.A.F., Parente, E., Cartaxo de Melo, A.M., Silva de Holanda, A., 2013. Optimization of composite catenary risers. Mar. Struct. 33, 1–20. https://doi.org/10.1016/j.marstruc.2013.04.002.

Gao, Q., Zhang, P., Duan, M., Yang, X., Shi, W., An, C., Zhongli Li, Z., 2018. Investigation on structural behavior of ring-stiffened composite offshore rubber hose under internal pressure. Appl. Ocean Res. 79 (1), 7–19. https://doi.org/10.1016/j.apor.2018.07.007.

Gillett, N., 2018. Design and Development of a Novel Deepwater Composite Riser. BEng Thesis. Engineering Department, Lancaster University, Lancaster, UK.

Hanonge, D., Luppi, A., 2010. Challenges of flexible riser systems in shallow waters. Paper No:OTC 20578. In: Proceedings of Annual Offshore Technology Conference. May 3–6, 2010, Houston, Texas, USA, pp. 1–10. https://doi.org/10.4043/20578-MS.

Hartman, D., Greenwood, M.E., Miller, D.M., 1996. *High Strength Glass Fibers* 2006 Repri. AGY, Aiken, South Carolina, USA. Available at: https://www.agy.com/wp-content/uploads/2014/03/High_Strength_Glass_Fibers-Technical.pdf, 8th September, 2021.

Hatton, S., 2012. Carbon fibre – a riser system enabler. Offshore Eng. 37 (1), 42–43. Available at: http://www.oedigital.com/engineering/item/696-carbon-fibre-–-a-riser-system-enabler, 8th September, 2021.

Hatton, S.A., Rumsey, L., Biragoni, P., Roberts, D., 2013. Development and Qualification of End Fittings for Composite Riser Pipe. In: Paper presented at the Offshore Technology Conference, Houston, Texas, USA, May 2013. https://doi.org/10.4043/23977-MS.

Hoen, C., 2003. Global behaviour of deep-water compliant composite risers. In: Conference: Deep Offshore Technology. November 2003, at: Marseille, France. Available at: https://www.researchgate.net/publication/276061070_GLOBAL_BEHAVIOUR_OF_DEEP-WATER_COMPLIANT_COMPOSITE_RISERS, 9th September, 2021.

Hossain, R., Carey, J.P., Mertiny, P., 2013. Framework for a combined netting analysis and Tsai-Wu-based design approach for braided and filament-wound composites. ASME. J. Pressure Vessel Technol 135 (3), 031204. https://doi.org/10.1115/1.4023431. June 2013.

Hou, Y., Yuan, J., Tan, Z., Witz, J., 2019. Application of an enhanced lazy wave flexible riser system in extreme shallow water with an external turret Moored FPSO. Paper number: OTC-29327-MS. May. In: Proceedings of Annual *Offshore Technology Conference*, pp. 1–8. https://doi.org/10.4043/29327-MS, 2019, Houston, Texas, USA.

Johnson, D.B., Salama, M.M., Long, J.R., Wang, S.S., 1998. Composite production riser - manufacturing development and qualification testing. In: Offshore Technology Conference - OTC 8665. May 4–7, 1998. OnePetro/OTC, Houston, Texas, USA, pp. 113–123. https://doi.org/10.4043/8665-MS.

Johnson, D.B., Baldwin, D.D., Long, J.R., 1999. Mechanical performance of composite production risers. In: Offshore Technology Conference - OTC 11008. OnePetro/OTC, Houston, Texas, USA, pp. 1–10. https://doi.org/10.4043/11008-MS. May 3–6, 1999.

Jones, R.M., 1999. Mechanics of Composite Materials, 2nd ed. Taylor & Francis, Philadelphia, USA.

Kaw, A.K., 2006. Mechanics of Composite Materials, 2nd ed. CRC Press; Taylor & Francis, Boca Raton, USA.

Kim, W.K., 2007. Composite Production Riser Assessment. PhD Thesis. Texas A & M University, Texas, USA. Available at: https://core.ac.uk/download/pdf/4272879.pdf. (Accessed 18 March 2021).

Kim, W., Ochoa, O.O., Miller, C.A., 2005a. Axial and burst analysis of offshore composite risers. In: Proceedings of the American Society for Composites. Philadelphia, PA, September 7-9, 2005.

Kim, W., Ochoa, O.O., Ward, E.G., Miller, C.A., 2005b. Structural response of composite production risers, 2005. In: Proceedings of the Fourth International Conference on Composite Materials for Offshore Operations. October 4-6, 2005. Houston, Texas, USA.

MagmaGlobal, 2016a. Composite riser OCYAN. "Materials selection for thermoplastic fibre reinforced risers". In: Deep Offshore International Conference, 2016. Available at: https://www.youtube.com/watch?v=FIrOP6PbUIQ. (Accessed 22 May 2021).

MagmaGlobal, 2016b. Magma m-pipe and IDP System Global Analysis. Magma Global Fact Sheet. Portsmouth, UK. Available at: https://www.magmaglobal.com/m-pipe/. (Accessed 22 May 2021).

MagmaGlobal, 2016c. Lightweight Riser Design Approach with m-pipe. Magma Global Fact Sheet. Portsmouth, UK. Available at: https://www.magmaglobal.com/lightweight-riser-design/. (Accessed 23 May 2021).

MagmaGlobal, 2016d. Ocyan - Magma Comp Risers. Available at: https://www.magmaglobal.com/risers/ocyan-compriser/. (Accessed 23 May 2021).

MagmaGlobal, 2016e. The m-pipe Lightweight Riser Solution. Magma Global Fact Sheet. Portsmouth, UK. Available at: http://www.magmaglobal.com. (Accessed 22 May 2021).

MagmaGlobal, 2015. Magma m-pipe® End Fittings, Monitoring and Bend Test. Available at: https://www.youtube.com/watch?v=kNoM32UZcgc. (Accessed 22 May 2021).

McGeorge, D., Sodahl, N., Moslemian, R., Horte, T., 2019. Hybrid and Composite Risers for Deep Waters and Aggressive Reservoirs. 14th Offshore Mediterranean Conference (OMC) and Exhibition. Ravenna, Italy.

MatWeb, 2018. AS4 PEEK Plus Carbon Fiber Reinforced Unidirectional – MatWeb Material Property Data. MatWeb Material Property Data. Available at: http://www.matweb.com/search/datasheet.aspx?matguid=1e8a25336d7645d8a24cbdd10ed2dd29&ckck=1. (Accessed 12 April 2018).

MatWeb, 2021a. Solvay 934 Epoxy-S2 Glass Fiber Reinforced Unidirectional – MatWeb Material Property Data. MatWeb Material Property Data. Available at: http://www.matweb.com/search/datasheettext.aspx?matguid=0e86c9201a2d45f7bb61f85b28a3e681. (Accessed 17 March 2021).

Matweb, 2021b. Solvay APC-2/IM7 PEEK with Carbon Fiber Reinforced Unidirectional Tape. Available at: http://www.matweb.com/search/datasheet.aspx?matguid=de8bbf7fdbe24953bd0fded027995092, 8th September, 2021.

Matweb, 2021c. Overview of Materials for Polyetheretherketone (unreinforced). Matweb [cited 2021]; Available from: http://www.matweb.com/search/DataSheet.aspx?MatGUID=2164cacabcde4391a596640d553b2ebe&ckck=1, 8th September, 2021.

Melve, B., Fjellheim, P., Raudeberg, S., Tanem, S.A., 2008. First Offshore Composite Riser Joint Proven on Heidrun. Offshore Magazine. Article 16761859, Issue 3 (March 1, 2008). Available at: https://www.offshore-mag.com/business-briefs/equipment-engineering/article/16761859/first-offshore-composite-riser-joint-proven-on-heidrun, 8th September, 2021.

Ochoa, O.O., Salama, M.M., 2005. Offshore composites: transition barriers to an enabling technology. Compos. Sci. Technol. 65, 2588–2596. https://doi.org/10.1016/j.compscitech.2005.05.019.

Ochoa, O.O., 2006. Composite Riser Experience and Design Guidance; MMS project number 490, Texas, USA. Available at: https://www.bsee.gov/sites/bsee.gov/files/tap-technical-assessment-program//490aa.pdf. (Accessed 13 March 2021).

Odijie, A.C., Quayle, S., Ye, J., 2017a. Wave induced stress profile on a paired column semisubmersible hull formation for column reinforcement. Eng. Struct. 143 (April), 77–90. https://doi.org/10.1016/j.engstruct.2017.04.013. Available at:

Odijie, A.C., Wang, F., Ye, J., 2017b. A review of floating semisubmersible hull systems: column stabilized unit. Ocean Eng. 144 (October 2016), 191–202. https://doi.org/10.1016/j.oceaneng.2017.08.020. Available at:

Ohiara, T.M., 2019. Facies, Diagenesis and Pore Characterisation of the Lower Carboniferous Hodder Mudstone Formation, Bowland Basin, UK. PhD Thesis. School of earth and environmental sciences, University of Manchester, Manchester, UK. Available at: https://www.research.manchester.ac.uk/portal/files/146385170/FULL_TEXT.PDF, 8th September, 2021.

Onna, M. Van, Gioccobi, S., de Boer, H., 2014. Evaluation of the first deployment of a composite downline in deepwater Brazil. In: IBP1852_14, Rio Oil & Gas Conference 2014. Brazil.

Onna, M. Van, O'Brien, P., 2011. A new thermoplastic composite riser for deepwater application. In: Subsea UK Conference. UK, pp. 1–23. Available at: https://www.subseauk.com/documents/martinvan onnasubsea2011presentation.pdf, 8th September, 2021.

Onna, M. Van, Lyon, J., 2017. Installation of World's 1st Subses a Thermoplastic Composite Pipe Jumper on Alder 2011. Available at: https://www.subseauk.com/documents/presentations/martin%20van%20onna%20-%20fields%20of%20the%20future%20-%20airborne.pdf, 8th September, 2021.

Peter, A., Jin, X., Fan, X., Eshiet, K.I.-I., Sheng, Y., Yang, D., 2022. Microscopy and image analysis of the micro-fabric and composition of saline rocks under different phase CO_2. J. Petrol. Sci. Eng. 208, 109411. https://doi.org/10.1016/j.petrol.2021.109411. January 2022.

Pham, D., Sridhar, N., Qian, X., Sobey, A.J., Achintha, M., Shenoi, A., 2016. A review on design, manufacture and mechanics of composite risers. Ocean Eng. 112, 82–96. https://doi.org/10.1016/j.oceaneng.2015.12.004.

Pham, D., Sridhar, N., Qian, X., Sobey, A.J., Achintha, M., Shenoi, A., 2014. Composite riser design and development – a review. Analysis and Design of Marine Structures V. In: 5th International Conference on Marine Structures, Southampton, United Kingdom, first ed. CRC Press, London, UK, pp. 1–8. Available at: http://eprints.soton.ac.uk/id/eprint/372798. 8th September, 2021.

Picard, D., Hudson, W., Bouquier, L., Dupupet, G., Zivanovic, I., 2007. Composite carbon thermoplastic tubes for deepwater applications. In: *Offshore Technology Conference* -OTC 19111, pp. 1–9. https://doi.org/10.4043/19111-MS. April 30–May 3, 2007; Houston, Texas, USA.

Qin, Q., Ye, J., 2015. Toughening Mechanisms in Composite Materials. A Volume in Woodhead Publishing Series in Composites Science and Engineering. Elsevier Publishers, UK. https://doi.org/10.1016/C2013-0-16514-2. Available at:

Rathnaweera, T., Ranjith, P., Perera, M., 2016. Experimental investigation of geochemical and mineralogical effects of CO_2 sequestration on flow characteristics of reservoir rock in deep saline aquifers. Sci. Rep. 6, 19362. https://doi.org/10.1038/srep19362.

Roberts, D., Hatton, S.A., 2013. Development and qualification of end fittings for composite riser pipe. In: *Offshore Technology Conference May 6th-9th, 2013. Paper Number: OTC-23977-MS*. OnePetro/OTC, Houston, Texas, USA. https://doi.org/10.4043/23977-MS.

Salama, M.M., Johnson, D.B., Long, J.R., 1998. Composite production riser testing and qualification. SPE Prod. Facil. 13, 170–177. https://doi.org/10.2118/50971-PA (1998).

Salama M., Spencer B.E. (2006). Metal lined composite risers in offshore applications. US 20040086341A1 Patent, USA. Available at: https://patents.google.com/patent/US20040086341A1/en (Accessed on 8th September, 2021).

Salama, M.M., Murali, J., Baldwin, D.D., Jahnsen, O., Meland, T., 1999. Design consideration for composite drilling riser. In: Offshore Technology Conference - OTC 11006. OnePetro/OTC, Houston, Texas, USA, pp. 1–11. https://doi.org/10.4043/11006-MS. May 3–6, 1999.

Salama, M.M., 1986. Lightweight materials for deepwater offshore structures. In: Offshore Technology Conference - OTC 5185. OnePetro/OTC, Houston, Texas, USA, pp. 297–304. https://doi.org/10.4043/5185-MS. May 5–8, 1986.

Salama, M.M., Stjern, G., Storhaug, T., Spencer, B., Echtermeyer, A., 2002. The first offshore field installation for a composite riser joint -OTC 14018. In: Offshore

Technology Conference. OnePetro, Houston, Texas, USA, pp. 1–7. https://doi.org/10.4043/14018-MS. May 6-9, 2002.
Sharma, A., Daggumati, S., Gupta, A., Van Paepegem, W., 2020. On the prediction of the bi-axial failure envelope of a UD CFRP composite lamina using computational micromechanics: Effect of microscale parameters on macroscale stress–strain behaviour. Composite Structures Volume 251. https://doi.org/10.1016/j.compstruct.2020.112605, 1 November 2020, 112605.
Saleh, H., 2015. The Benefits of Composite Materials in Deepwater Riser Applications: MCE Deepwater Development CONFERENCE. Available at: https://2hoffshore.com/wp-content/uploads/2016/01/2015-MCE-The-Benefits-Of-Composite-Materials-In-Deepwater-Riser-Applications.pdf, 8th September, 2021.
Singh, M., Ahmad, S., 2014. Local stress analysis of composite production riser under random sea. *Proceedings of the ASME 2014 33rd International Conference on Ocean, Offshore and Arctic Engineering*, OMAE 2014. Volume 4B: Structures, Safety and Reliability. San Francisco, California, USA. June, 8–13, V04BT02A013. ASME. https://doi.org/10.1115/OMAE2014-23983.
Smits, A., Neto, T.B., Boer, H. De, 2018. Thermoplastic composite riser development for ultradeep water. In: Offshore Technology Conference. Paper OTC-29061-MS. Houston, Texas, USA, pp. 1–9. https://doi.org/10.4043/29061-MS.
Solvay, 2017. APC-2 PEEK Thermoplastic Polymer Prepreg [cited 2020]; Available at: https://www.solvay.com/en/product/apc-2-peek-thermoplastic-composite-tapes, 8th September, 2021.
Sparks, C.P., 2018. Fundamentals of Marine Riser - Basic Principles and Simplified Analyses, second ed. PennWell Books, Oklahoma, USA.
Sparks, C.P., Odru, P., Metivaud, Guy, Le Floc'h, Christian, 1992. Composite riser tubes: defect tolerance assessment and nondestructive testing. In: Offshore Technology Conference - OTC 6894. OnePetro/OTC, Houston, Texas, USA, pp. 191–198. https://doi.org/10.4043/6894-MS. May 4–7, 1992.
Sparks, C.P., Odru, P., Bono, H., Metivaud, G., 1988. Mechanical testing of high-performance composite tubes for TLP production risers. In: Offshore Technology Conference - OTC 5797. OnePetro/OTC, May 2–5, 1988, Houston, Texas, USA, pp. 467–472. https://doi.org/10.4043/5797-MS.
Sparks, C.P., Odru, P., 1989. High-performance composites for deepwater risers. In: Paper Presented at the Diverless and Deepwater Technology: Proceedings of an International Conference, February 22-23, 1989. Paper Number: SUT-AUTOE-v19-065; London, UK. Available at: https://onepetro.org/SUTDDT/proceedings-abstract/AUTOE19/All-AUTOE19/SUT-AUTOE-v19-065/2770, 8th September, 2021.
Steuten, B., Onna, M. Van, 2016. Reduce project and life cycle cost with TCP flowline. In: Offshore Technology Conference. Kuala Lumpar, Malaysia, pp. 1–10. https://doi.org/10.4043/26512-MS, 22nd-25th March, 2016. Paper OTC-26512-MS.
Sun, C.T., Li, S., 1988. Three-dimensional effective elastic constant for thick laminates. J. Compos. Mater. 22, 629–639. https://doi.org/10.1177/2F002199838802200703.
Sun, X.S., Chen, Y., Tan, V.B.C., Jaiman, R.K., Tay, T.E., 2013. "Homogenization and Stress Analysis of Multilayered Composite Offshore Production Risers." ASME. J. Appl. Mech 81 (3). https://doi.org/10.1115/1.4024695. March 2014, 031003.
Sun, X.S., Tan, V.B.C., Chen, Y., et al., 2014a. Stress analysis of multi-layered hollow anisotropic composite cylindrical structures using the homogenization method. Acta Mech. 225, 1649–1672. https://doi.org/10.1007/s00707-013-1017-9.
Sun, X.S., Tan, V.B.C., Tan, L.B., Chen, Y., Jaiman, R.K., Tay, T.E., 2014b. Fatigue life prediction of composite risers due to vortex-induced vibration (VIV), 2014. Int. J. Fract. Fatig. Wear 2, 207–213. Proceedings of the 3rd International Conference on Fracture, Fatigue and Wear, Kitakyushu, Japan. Available at. https://www.researchgate.net/publication/265374630_Fatigue_life_prediction_of_composite_risers_due_to_vortex-induced_vibration_VIV (Accessed on: 14th January, 2022).
Tamarelle, P.J.C., Sparks, C.P., 1987. High-performance composite tubes for offshore applications. In: Offshore Technology Conference - OTC 5384. OnePetro/OTC, Houston, Texas, USA, pp. 255–260. https://doi.org/10.4043/5384-MS.
Tan, L.B., et al., 2015. Coupled fluid–structure simulations for evaluating a performance of full-scale deepwater composite riser. Ocean Eng. 94, 19–35. https://doi.org/10.1016/j.oceaneng.2014.11.007. Available at:
Tew, B.W., 1995. Preliminary design of tubular composite structures using netting theory and composite degradation factors. ASME. J. Pressure Vessel Technol. 117 (4), 390–394. https://doi.org/10.1115/1.2842141. November 1995.
Toray, 2008. T700S Data Sheet, Santa Ana, CA, USA. Available at: https://www.toraycma.com/file_viewer.php?id=4459%0A. (Accessed 12 April 2018).
Wan, L., Ismail, Y., Zhu, C., 2020. Computational micromechanics-based prediction of the failure of unidirectional composite lamina subjected to transverse and in-plane shear stress states. J. Compos. Mater. 54 (24), 3637–36541. https://doi.org/10.1177/0021998320918015.
Wang, C., Shankar, K., Morozov, E.V., 2015. Global design and analysis of deep sea FRP composite risers under combined environmental loads. Adv. Compos. Mater. 26 (1), 79–98. https://doi.org/10.1080/09243046.2015.1052187.
Wang, C., Shankar, K., Ashraf, M.A., Morozov, E.V., Ray, T., 2016. Surrogate-assisted optimisation design of composite riser. Proceedings of the Institution of Mechanical Engineers. Part L: Journal of Materials: Design and Applications 230 (1), 18–34. https://doi.org/10.1177/1464420714539304, 2016.
Wang, C., Shankar, K., Morozov, E.V., 2017. Tailored design of top-tensioned composite risers for deep-water applications using three different approaches. Adv. Mech. Eng. 9 (1), 1–18. https://doi.org/10.1177/1687814016684271.
Wang, C., Shankar, K., Morozov, E.V., 2012a. Design of composite risers for minimum weight. World academy of science, enineering and technology, 2012 Int. J. Mech. Aero. Ind. Mech. Manuf. Eng. 6 (12), 2627–2636. Available at: scholar.waset.org/1999.8/4236.
Wang, C., Shankar, K., Morozov, E.V., 2012b. Design of deep sea composite risers under combined environmental loads. In: Proceedings of Diversity in Composites Conference, 15th-16th March, 2012. Leura, New South Wales, Australia, pp. 1–14.
Wang, C., Shankar, K., Morozov, E.V., 2011a. Tailoring of composite reinforcements for weight reduction of offshore production risers. Appl. Mech. Mater. 66–68 (2011), 1416–1421. https://doi.org/10.4028/www.scientific.net/AMM.66-68.1416.
Wang, C., Shankar, K., Morozov, E.V., 2011b. Local design of composite risers under burst, tension and collapse cases. Aug 22nd 2011. In: Proceedings of 18th International Conference on Composite Materials (ICCM18), pp. 1–6. Available at: www.iccm-central.org/Proceedings/ICCM18Proceedings/. (Accessed 12 December 2021).
Wang, C., Shankar, K., Morozov, E.V., 2015. Tailored local design of deep sea FRP composite risers. Advanced Composite Materials 24 (4), 375–397. https://doi.org/10.1080/09243046.2014.898438.
Wang, C., Sun, M., Shankar, K., Xing, S., Zhang, L., 2018. CFD simulation of vortex induced vibration for FRP composite riser with different modeling methods. Appl. Sci. 8 (5), 684. https://doi.org/10.3390/app8050684.
Wang, C., Ge, S., Sun, M., Jia, Z., Han, B., 2019. Comparative study of vortex-induced vibration of FRP composite risers with large length to diameter ratio under different environmental situations. Appl. Sci. 9 (3), 517. https://doi.org/10.3390/app9030517.
Ward, E.G., Ochoa, O.A., Kim, W., 2007. A Comparative Risk Analysis of Composite and Steel Production Risers. Phase I & II Final Project Report, Prepared for the Minerals Management Service, MMS Project Number 490 and OTRC Industry Consortium, OTRC Library Number: 3/07A180. Available at: https://www.bsee.gov/sites/bsee.gov/files/tap-technical-assessment-program/490ab.pdf, 16th December, 2021.
Wilkins, J., 2016. Qualification of composite pipe, OTC-27179-MS. In: Offshore Technology Conference, pp. 1–15. https://doi.org/10.4043/27179-MS. May 2–5, 2016. Houston, Texas, USA.
Xia, M., Takayanagi, H., Kemmochi, K., 2001. Analysis of multi-layered filament-wound composite pipes under internal pressure. Compos. Struct. 53 (4), 483–491. https://doi.org/10.1016/S0263-8223(01)00061-7.
Ye, J., Cai, H., Liu, L., Zhai, Z., Amaechi, C.V., Wang, Y., Wan, L., Yang, D., Chen, X., Ye, J., 2021. Microscale intrinsic properties of hybrid unidirectional/woven composite laminates: Part I: experimental tests. Compos. Struct. 262 (113369) https://doi.org/10.1016/j.compstruct.2020.113369.
Ye, J.J., Wang, Y.W., Li, Z.W., Saafi, M., Jia, F., Huang, B., Ye, J., 2020. Failure analysis of fiber-reinforced composites subjected to coupled thermo-mechanical loading. Compos. Struct. 235 (2020) https://doi.org/10.1016/j.compstruct.2019.111756. Article 111756.
Ye, J., 2003. Laminated Composite Plates and Shells: 3D Modelling. Springer-Verlag, London, UK.
Ye, J., 2016. *Structural and Stress Analysis: Theories, Tutorials and Examples* Second. CRC Press, New York, USA.
Ye, J., Soldatos, K.P., 1995. Three-dimensional buckling analysis of laminated composite hollow cylinders and cylindrical panels. Int. J. Solid Struct. 32 (13), 1949–1962. https://doi.org/10.1016/0020-7683(94)00217-K.
Zhang, H., Tong, L., Addo, M.A., 2021. Mechanical analysis of flexible riser with carbon fiber composite tension armor. Journal of Composites Science 5 (1), 3. https://doi.org/10.3390/jcs5010003.
Zhou, Y., Duan, M.L., Ma, J.M., Sun, G.M., 2018. Theoretical analysis of reinforcement layers in bonded flexible marine hose under internal pressure. Eng. Struct. 168, 384–398. https://doi.org/10.1016/j.engstruct.2018.04.061.
Zou, J., 2008. Dynamic responses of a dry tree semisubmersible platform with ram style tensioners in the post-katrina irregular seas. In: Proceedings of the Eighteenth International Society of Offshore and Polar Engineering Conference, July 6-11, 2008. Vancouver, Canada. Paper No. ISOPE-2008-DA-04. Available at. http://publications.isope.org/proceedings/ISOPE/ISOPE%202008/papers/I08DA-04Zou.pdf.
Zou, J., Poll, P., Antony, A., Das, S., Padmanabhan, R., Vinayan, V., Parambath, A., 2014. VIM model testing and VIM induced mooring fatigue of a dry tree paired column semisubmersible platform. In: Offshore Technology Conference 2014. OTC, Houston, Texas, USA, 25427. 2014. https://doi.org/10.4043/25427-MS.