OTC OTC-24306-MS

ON THE SPECIFICATIONS OF FLEXIBLE COMPOSITE BALL SOCKET JOINT PIPE CHARACTERIZED BY BARREL SHELL MODEL

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This paper was prepared for presentation at the Offshore Technology Conference Brasil held in Rio de Janeiro, Brazil, 29–31 October 2013.

Abstract

Pipelines for deep-water application should be designed to be extremely flexible to ease the installation procedures. Such flexibility will improve the bending instabilities of reeled pipelines during spooling of initially straight or laying of initially bent pipe. Also during construction, pipeline flexibility could be exploited to connect pipelines and risers to floaters, manifolds, wellheads, buoys, and platforms. Therefore, the proposed flexible pipe is designed to be positionable and bendable enough to fit the above requirements. The pipe is comprises a series of interconnected ball-and-socket sections forming a liner and a fluid-tight cover, one or more helical wounding layers applied to the internal liner for absorbing tension loads, and one or more additional helical wounding layers applied for absorbing bending loads. In order to form a liner, the ball-and-socket segment will passes through a die, while a thread guide applies a plurality of reinforcing threads in a particular pattern to the exterior surface thereof to keep the segments to be snappingly engageable and maintain the pipe flexibility without significantly increasing in the thickness of the pipe wall or weight. The ball and socket segments are assumed manufactured from a lightweight composite material consisting of epoxied matrix reinforced by long continuous fibers. The socket segment was assumed a stiffer ring. Therefore, this paper will emphases on the design parameters of the ball joint that form the pipe by modeling it as laminated composite barrel shell and examining its elastic deformations capacity under pure bending conditions (e.g., typical reeling installation condition). To this aim, a straightforward treatment of the problem is presented via using Hamilton's principle and based on the first order shear deformation theories. The solution of the laminated composite barrel shell was formulated to follow exactly a simply supported boundary condition. Finally, the in-plane stresses and inter-laminar stresses were evaluated for wide range of loading conditions.

Introduction

The so called; a flexible ball socket joint, thread flexible round, or ball joint pipe is anticipated to be used in particular, although not exclusive, as utility in offshore or onshore for the transportation of petroleum oil and gas or other fluids. Such pipes are made up of a number of substantially rigid composite ball and socket segments, each segment combine the low weight and high strength properties. Thereby the pipe becomes extremely bendable and sufficiently flexible to spool onto reel for the purpose of reeling installation. Although flexible pipes are well known in the art and are for example they described in the standards; ANSI/API 17 B; Recommended Practice for Flexible Pipe, and ANSI/API 17J; Specification for Unbonded Flexible Pipe, the ball joint pipes haven't modeled yet. In this paper the proposed flexible ball socket joint pipe was invented to fulfill a number of requirements:

1. First of all the pipe was designed to have a very high mechanical strength to withstand the forces it will be subjected to during transportation, deploying and in operation.
2. The ball segments was designed to withstand the internal pressure that are usually considered very high and may vary considerably along the length of the pipe, in particular when applied at varying water depths. Therefore, the ball segments will be stiffer enough to resist the different in pressure, result in preventing the pipeline damage such as burst and collapse.
3. The flexible pipe was designed from specific composite materials to be highly non-corrosive and chemical resistance.
4. The proposed ball joint pipe was designed to keep the weight of the pipe relatively low, both in order to reduce transportation cost and deployment cost but also in order to reduce risk of damaging the pipe during deployment.

Geometry Description

Assume a flexible pipe comprising a series or chain of interconnected composite ball joint segments inserted inside a socket segments, (i.e., segments attached end to end surrounding a central space). The segments, when snappingly engaged, create frictionally positionable ball and socket joints. In order to prevent the pipe segments from becoming detached from each other, a thread guide applies a plurality of reinforcing threads in a particular pattern to the exterior surface of the socket sections, allow the said socket sections communicate to provide a continuous passageway through said series of interconnected sections. The said reinforcing could be carbon, glass or armor fiber wrapped helically to preclude the disassembling of the pipe segments Figure 1.a. The socket sections have an accurate surfaces and landings dimension and are maintained in spaced relation allowing the insertion of ball sections into the central space maximizing the pipe flexibility. Therefore, the reinforcements and the ball socket joints will form a corrugated composite tube that is unitary in construction covered with elastic filler filled in valley gaps between corrugation hills on an outer peripheral side to provide a continuous barrier layer against permeation of conveyed fluid and protect the fibers. Although the pipe is comprising another element such as: an external thermoplastic fluid-tight cover and one or more helical wounding tape stacks applied to the internal liner for absorbing axial and bending loads, the current research will emphases on the design parameters of the ball joint segments only. The ball segments are found adequate to thick laminated composite barrel shell. The barrel shell element is assumed to be simply supported which is passable if we considered the ball joint pipe undergo reeling Figure 1.b.

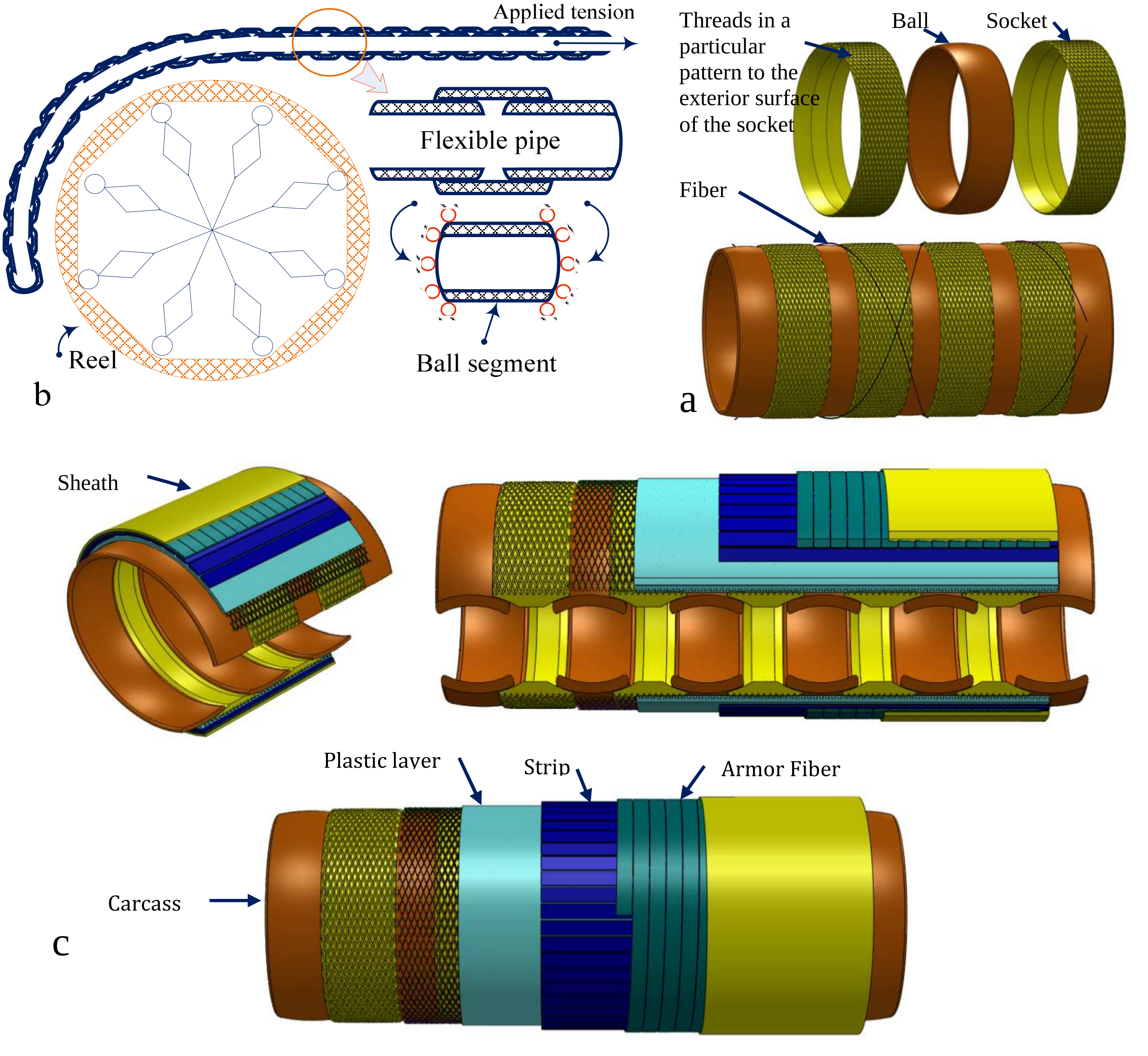


Figure 1.The flexible ball socket joint pipe.

Equations of Motion

Based on the laminated composite thick cylindrical shell theories [1] the equations of motion could be drawn as:

$$\frac{\partial}{\partial\alpha}N_{\alpha} + \frac{\partial}{\partial\beta}N_{\beta\alpha} + \frac{Q_{\alpha}}{R_{\alpha}} + \mathcal{F}_{\alpha} = \bar{I}_1\frac{\partial^2 u_o}{\partial t^2} + \bar{I}_2\frac{\partial^2\psi_{\alpha}}{\partial t^2}, \qquad \frac{\partial}{\partial\beta}N_{\beta} + \frac{\partial}{\partial\alpha}N_{\alpha\beta} + \frac{Q_{\beta}}{R_{\beta}} + \mathcal{F}_{\beta} = \bar{I}_1\frac{\partial^2 v_o}{\partial t^2} + \bar{I}_2\frac{\partial^2\psi_{\beta}}{\partial t^2}$$

$$-\left(\frac{N_{\alpha}}{R_{\alpha}} + \frac{N_{\beta}}{R_{\beta}}\right) + \frac{\partial}{\partial\alpha}Q_{\alpha} + \frac{\partial}{\partial\beta}Q_{\beta} + \mathcal{F}_n = \bar{I}_1\frac{\partial^2 w_o}{\partial t^2}$$

$$\frac{\partial}{\partial\alpha}M_{\alpha} + \frac{\partial}{\partial\beta}M_{\beta\alpha} - Q_{\alpha} + \frac{P_{\alpha}}{R_{\alpha}} + \mathcal{C}_{\alpha} = \bar{I}_2\frac{\partial^2 u_o}{\partial t^2} + \bar{I}_3\frac{\partial^2\psi_{\alpha}}{\partial t^2}, \qquad \frac{\partial}{\partial\beta}M_{\beta} + \frac{\partial}{\partial\alpha}M_{\alpha\beta} - Q_{\beta} + \frac{P_{\beta}}{R_{\beta}} + \mathcal{C}_{\beta} = \bar{I}_2\frac{\partial^2 u_o}{\partial t^2} + \bar{I}_3\frac{\partial^2\psi_{\beta}}{\partial t^2}.$$

Kinetic Equations

The force and moment resultants could be drawn as:

$$\begin{Bmatrix} N_{\alpha} \\ N_{\beta} \\ Q_{\beta} \\ Q_{\alpha} \\ N_{\alpha\beta} \\ N_{\beta\alpha} \\ M_{\alpha} \\ M_{\beta} \\ P_{\beta} \\ P_{\alpha} \\ M_{\alpha\beta} \\ M_{\beta\alpha} \end{Bmatrix} = \begin{bmatrix}
\bar{\varsigma}^1_{11} & \varsigma^1_{12} & \varsigma^1_{14} & \bar{\varsigma}^1_{15} & \bar{\varsigma}^1_{16} & \varsigma^1_{16} & \bar{\varsigma}^2_{11} & \varsigma^2_{12} & \varsigma^2_{14} & \bar{\varsigma}^2_{15} & \bar{\varsigma}^2_{16} & \varsigma^2_{16} \\
 & \tilde{\varsigma}^1_{22} & \tilde{\varsigma}^1_{24} & \varsigma^1_{25} & \varsigma^1_{26} & \tilde{\varsigma}^1_{26} & \varsigma^2_{12} & \tilde{\varsigma}^2_{22} & \tilde{\varsigma}^2_{24} & \varsigma^2_{25} & \varsigma^2_{26} & \tilde{\varsigma}^2_{26} \\
 & & \tilde{\varsigma}^1_{44} & \varsigma^1_{45} & \varsigma^1_{46} & \tilde{\varsigma}^1_{46} & \varsigma^2_{14} & \tilde{\varsigma}^2_{24} & \tilde{\varsigma}^2_{44} & \varsigma^2_{45} & \varsigma^2_{46} & \tilde{\varsigma}^2_{46} \\
 & & & \bar{\varsigma}^1_{55} & \bar{\varsigma}^1_{56} & \varsigma^1_{56} & \bar{\varsigma}^2_{15} & \varsigma^2_{25} & \varsigma^2_{45} & \bar{\varsigma}^2_{55} & \bar{\varsigma}^2_{56} & \varsigma^2_{56} \\
 & & & & \bar{\varsigma}^1_{66} & \varsigma^1_{66} & \bar{\varsigma}^2_{16} & \varsigma^2_{26} & \tilde{\varsigma}^2_{46} & \varsigma^2_{56} & \bar{\varsigma}^2_{66} & \varsigma^2_{66} \\
 & & & & & \tilde{\varsigma}^1_{66} & \varsigma^2_{16} & \varsigma^2_{26} & \tilde{\varsigma}^2_{46} & \varsigma^2_{56} & \varsigma^2_{66} & \tilde{\varsigma}^2_{66} \\
 & & & & & & \bar{\varsigma}^3_{11} & \varsigma^3_{12} & \varsigma^3_{14} & \bar{\varsigma}^3_{15} & \bar{\varsigma}^3_{16} & \varsigma^3_{16} \\
 & & & & & & & \tilde{\varsigma}^3_{22} & \tilde{\varsigma}^3_{24} & \varsigma^3_{25} & \varsigma^3_{26} & \tilde{\varsigma}^3_{26} \\
 & & \mathit{Symmetric} & & & & & & \tilde{\varsigma}^3_{44} & \varsigma^3_{45} & \varsigma^3_{46} & \tilde{\varsigma}^3_{46} \\
 & & & & & & & & & \bar{\varsigma}^3_{55} & \bar{\varsigma}^3_{56} & \varsigma^3_{56} \\
 & & & & & & & & & & \bar{\varsigma}^3_{66} & \varsigma^3_{66} \\
 & & & & & & & & & & & \tilde{\varsigma}^3_{66}
\end{bmatrix} \begin{Bmatrix} \varepsilon_{o\alpha} \\ \varepsilon_{o\beta} \\ \varepsilon_{o\beta\zeta} \\ \varepsilon_{o\alpha\zeta} \\ \varepsilon_{o\alpha\beta} \\ \varepsilon_{o\beta\alpha} \\ \varepsilon_{1\alpha} \\ \varepsilon_{1\beta} \\ \varepsilon_{1\beta\zeta} \\ \varepsilon_{1\alpha\zeta} \\ \varepsilon_{1\alpha\beta} \\ \varepsilon_{1\beta\alpha} \end{Bmatrix}$$

Where $[\bar{*}]^{\mathrm{n}}_{\mathrm{ij}} = [*]^{\mathrm{n}}_{\mathrm{ij}} - \mathrm{C_o}[*]^{\mathrm{n+1}}_{\mathrm{ij}}$, $[\tilde{*}]^{\mathrm{n}}_{\mathrm{ij}} = [*]^{\mathrm{n}}_{\mathrm{ij}} + \mathrm{C_o}[*]^{\mathrm{n+1}}_{\mathrm{ij}}$, $\mathrm{C_o} = (1/R_{\alpha} + 1/R_{\beta})$, and $\varsigma^p_{ij} \to p = 1,2,3,4;$ is the stiffness properties and the superscript indicate to understand the differences between the extensional, extensional-bending and bending stiffness coefficients, which are defined as follows:

$$\underbrace{\left(\varsigma^1_{\mathrm{ij}}, \varsigma^2_{\mathrm{ij}}, \varsigma^3_{\mathrm{ij}}, \varsigma^4_{\mathrm{ij}}\right)}_{(i,j=1,2,6)} = \sum_{k=1}^{N}\int_{h_{k-1}}^{h_k} \hat{\varsigma}^k_{ij}\,(1,\zeta,\zeta^2,\zeta^3)\,d\zeta, \quad \underbrace{\left(\varsigma^1_{\mathrm{ij}}, \varsigma^2_{\mathrm{ij}}, \varsigma^3_{\mathrm{ij}}, \varsigma^4_{\mathrm{ij}}\right)}_{(i,j=4,5)} = K_i^2\sum_{k=1}^{N}\int_{h_{k-1}}^{h_k} \hat{\varsigma}^k_{ij}\,(1,\zeta,\zeta^2,\zeta^3)\,d\zeta, \quad \mathit{and}\ \text{all other}\ \varsigma \equiv 0$$

where $\hat{\varsigma}^k_{ij}$ is the transformed properties of orthotropic materials. This method gives a solution for the same choice of deep shell stiffness coefficient, also K_{i} and K_{j} are shear correction coefficients, typically taken at 5/6 (Timoshenko 1921). In addition, h_{k} is the distance from the mid-surface to the surface of the k^{th} layer having the farthest ζ-coordinate.

Kinematic Equations

According to the Codazzi-Gauss geometrical sense, the following representation of the 3-D displacement field for barrel shell theory is postulated:

$$\varepsilon_{o\alpha} = \frac{\partial u_o}{\partial\alpha} + \frac{w_o}{R_{\alpha}}, \quad \varepsilon_{o\alpha\beta} = \frac{\partial v_o}{\partial\alpha}, \quad \varepsilon_{1\alpha} = \frac{\partial\psi_{\alpha}}{\partial\alpha}, \quad \varepsilon_{1\alpha\beta} = \frac{\partial\psi_{\beta}}{\partial\alpha}, \quad \varepsilon_{o\alpha\zeta} = \frac{\partial w_o}{\partial\alpha} - \frac{u_o}{R_{\alpha}} + \psi_{\alpha}, \quad \psi_{\beta} = \frac{v_o}{R_{\beta}} - \frac{\partial w_o}{\partial\beta}$$

$$\varepsilon_{o\beta} = \frac{\partial v_o}{\partial\beta} + \frac{w_o}{R_{\beta}}, \quad \varepsilon_{o\beta\alpha} = \frac{\partial u_o}{\partial\beta}, \quad \varepsilon_{1\beta} = \frac{\partial\psi_{\beta}}{\partial\beta}, \quad \varepsilon_{1\beta\alpha} = \frac{\partial\psi_{\alpha}}{\partial\beta}, \quad \varepsilon_{o\beta\zeta} = \frac{\partial w_o}{\partial\beta} - \frac{v_o}{R_{\beta}} + \psi_{\beta}, \quad \psi_{\alpha} = \frac{u_o}{R_{\alpha}} - \frac{\partial w_o}{\partial\alpha}$$

where, $\mathrm{u_o}$, $\mathrm{v_o}$ and $\mathrm{w_o}$ are the mid-surface displacements and ψ_{α} and ψ_{β} are midsurface rotations of the shell.

Analytical solution

Having applied the Navier' solution [2], the equations of motion can be written in terms of displacements as $\left(\mathcal{K}_{\mathrm{ij}} + \lambda^2\mathcal{M}_{\mathrm{ij}}\right)\{\Delta\} = \{\mathcal{F}\}$. Where $\mathcal{K}_{\mathrm{ij}}$ is the stiffness matrix and $\mathcal{M}_{\mathrm{ij}}$ is the mas matrix, $\{\mathcal{F}\}$ is the applied force, $\{\Delta\}^t = \left\{U_{mn}, V_{mn}, W_{mn}, \Psi^{\alpha}_{mn}, \Psi^{\beta}_{mn}\right\}$, and λ^2 is the eigenvalue of the problem. The configuration of the $\bar{\mathcal{K}}_{\mathrm{ij}}$ terms for the SS, cross-ply and rectangular plane form is listed below

$$\mathcal{K}_{11}=-\tilde{\varsigma}_{11}^{1}\alpha_m^2-\tilde{\varsigma}_{66}^{1}\beta_n^2-\frac{\tilde{\varsigma}_{55}^{1}}{R_\alpha^2},\ \mathcal{K}_{12}=-(\varsigma_{12}^{1}+\varsigma_{66}^{1})\alpha_m\beta_n\,,\ \mathcal{K}_{22}=-\tilde{\varsigma}_{22}^{1}\beta_n^2-\tilde{\varsigma}_{66}^{1}\alpha_m^2-\frac{\tilde{\varsigma}_{44}^{1}}{R_\beta^2},$$

$$\mathcal{K}_{13}=\left(\frac{\tilde{\varsigma}_{11}^{1}+\tilde{\varsigma}_{55}^{1}}{R_\alpha}+\frac{\varsigma_{12}^{1}}{R_\beta}\right)\alpha_m,\ \mathcal{K}_{23}=\left(\frac{\varsigma_{12}^{1}}{R_\alpha}+\frac{\tilde{\varsigma}_{22}^{1}+\tilde{\varsigma}_{44}^{1}}{R_\beta}\right)\beta_n\,,\ \mathcal{K}_{33}=-\tilde{\varsigma}_{44}^{1}\beta_n^2-\tilde{\varsigma}_{55}^{1}\alpha_m^2-\left(\frac{\tilde{\varsigma}_{11}^{1}}{R_\alpha^2}+\frac{2\varsigma_{12}^{1}}{R_\alpha R_\beta}+\frac{\tilde{\varsigma}_{22}^{1}}{R_\beta^2}\right),$$

$$\mathcal{K}_{14}=-\tilde{\varsigma}_{11}^{2}\alpha_m^2-\tilde{\varsigma}_{66}^{2}\beta_n^2+\frac{\tilde{\varsigma}_{55}^{1}}{R_\alpha},\ \mathcal{K}_{24}=-(\varsigma_{12}^{2}+\varsigma_{66}^{2})\alpha_m\beta_n\,,\ \mathcal{K}_{34}=\left(-\tilde{\varsigma}_{55}^{1}+\frac{\tilde{\varsigma}_{11}^{2}}{R_\alpha}+\frac{\varsigma_{12}^{2}}{R_\beta}\right)\alpha_m,$$

$$\mathcal{K}_{44}=-\tilde{\varsigma}_{55}^{1}-\tilde{\varsigma}_{11}^{3}\alpha_m^2-\tilde{\varsigma}_{66}^{3}\beta_n^2,\ \mathcal{K}_{15}=-(\varsigma_{12}^{2}+\varsigma_{66}^{2})\alpha_m\beta_n-\frac{\tilde{\varsigma}_{45}^{1}}{R_\alpha},\ \mathcal{K}_{25}=-\tilde{\varsigma}_{22}^{2}\beta_n^2-\tilde{\varsigma}_{66}^{2}\alpha_m^2+\frac{\tilde{\varsigma}_{44}^{1}}{R_\beta}$$

$$\mathcal{K}_{35}=\left(-\tilde{\varsigma}_{44}^{1}+\frac{\varsigma_{12}^{2}}{R_\alpha}+\frac{\tilde{\varsigma}_{22}^{2}}{R_\beta}\right)\beta_n\,,\ \mathcal{K}_{45}=-(\varsigma_{12}^{3}+\varsigma_{66}^{3})\alpha_m\beta_n\,,\ \mathcal{K}_{55}=-\tilde{\varsigma}_{44}^{1}-\tilde{\varsigma}_{66}^{3}\alpha_m^2-\tilde{\varsigma}_{22}^{3}\beta_n^2$$

While the mass matrix diagonal is housed by $\bar{I}_1$, $\bar{I}_1$, $\bar{I}_1$, $\bar{I}_2$, and $\bar{I}_3$ respectively from the upper left corner. The inertia terms was defined as:

$$\bar{I}_j=\left[I_j+I_{j+1}\left(\frac{R_\alpha+R_\beta}{R_\alpha R_\beta}\right)+\frac{I_{j+2}}{R_\alpha R_\beta}\right],\qquad for\ j=1,2,3,\qquad \text{and}\ [I_1,I_2,I_3,I_4,I_5]=\sum_{k=1}^{N}\int_{h_{k-1}}^{h_k}I^k\,(1,\zeta,\zeta^2,\zeta^3,\zeta^4,\zeta^5)d\zeta,$$

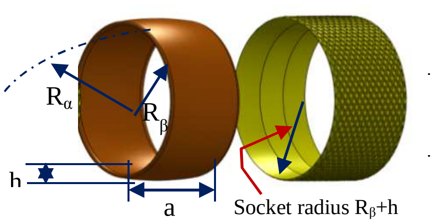
where I^k is the mass density of the kth layer of the shell per unit mid-surface area.

Results and Discussion

The in-plane and inter-laminar stresses of a ball element assumed made of common composite materials are evaluated for wide range of loading conditions. In order to define parametrically the number of configurations of ball segments that could be treated as laminated composite barrel shell element, a parametric study was implemented. Table 1, shows that the ball segments could be modeled by both thick or thin barrel shell theory but only few sets of ball dimensions found give more industrial sense (i.e., the sets that highlighted by red). Although, these sets could be used, the proposed ball socket joint pipe required a ball segment of shape equal to spherical shell that is chopped from bottom and top, which is adequate to the barrel shell of $(a/R_\beta)=(a/R_\alpha)=0.5$. Therefore, the set of (40cm,40cm,20cm) represnting $R_\alpha,\ R_\beta,\ and\ a$ respectively is selected in the current analysis. Table 2 displays the in-plane and inter-laminar stresses of ball segment as a part of ball socket joint pipe undergo pure bending. Results reveal that composite material CFRP appears more flexible than Gl-Ep and Gr-Ep. However, Br-Ep is found to exhibit rigid behavior. The nominated composite materials are found relevant for fabricating a ball socket joint pipe.

Table 1. The ball designe parameters.

a/R_β	a/R_α	R_β/h							
		10			20			50	
		Thickness in cm							
		0.5	1.0	2.0	0.5	1.0	2.0	0.5	1.0
8	0.5	5,80,40	10,160,80	20,320,160	10,160,80	20,320,160			
	0.1	5,400,40	10,800,80	20,1600,160	10,800,80	20,640,160			
4	0.5	5,40,20	10,80,40	20,160,80	10,80,40	20,160,80			
	0.1	5,200,20	10,400,40	20,800,80	10,400,40	20,800,80			
2	0.5	5, 20,10	10,40,20	20,80,40	10,40,20	20,80,40			
	0.1	5,100,10	10,200,20	20,400,40	10,200,20	20,400,40			
1	0.5	5,10, 5	10,20,10	20,40,20	10,20,10	20,40,20	40,80,40	25,50,25	50,100,50
	0.1	5,50, 5	10,100,10	20,200,20	10,100,10	20,200,20	40,400,40	25,250,25	50,500,50
0.5	0.5	5, 5, 2.5	10,10,5	20,20,10	10,10,5	20,20,10	40,40,20	25,25,12.5	50,50,25
	0.1	5,25, 2.5	10,50,5	20,100,10	10,50,5	20,100,10	40,200,20	25,125,12.5	50,250,25



The set of numbers inside table are representing the ball parameters $R_\alpha,\ R_\beta,\ and\ a$ respectively all in centimeter.

Table 2. The in-plane and inter-laminar stresses that induced into a ball segment made of some of common composite materials.

Material	Unit Load	$\bar{\sigma}_\alpha$	$\bar{\sigma}_\beta$	$\bar{\sigma}_{\alpha\beta}$	$\bar{\sigma}_{\alpha\zeta}^{k=1,3}$	$\bar{\sigma}_{\beta\zeta}^{k=2,4}$
		$\sigma_\alpha\left(h^2/P_o\alpha^2\right)$	$\sigma_\beta\left(h^2/P_o\alpha^2\right)$	$\sigma_{\alpha\beta}\left(h^2/P_o\alpha^2\right)$	$\sigma_{\alpha\zeta}\left(h/P_o\alpha\right)$	$\sigma_{\beta\zeta}\left(h/P_o\alpha\right)$
Gl-Ep	1	0.0779	-0.0316	0.0662	0.0774	0.0578
	3	0.2338	-0.0948	0.1986	0.2322	0.1733
	5	0.3897	-0.1580	0.3311	0.3870	0.2888
	7	0.5456	-0.2211	0.4635	0.5417	0.4043
Gr-Ep	1	0.1359	-0.0122	0.0422	0.0796	0.0332
	3	0.4077	-0.0365	0.1266	0.2389	0.0995
	5	0.6795	-0.0609	0.2109	0.3981	0.1659
	7	0.9514	-0.0853	0.2953	0.5574	0.2322
Br-Ep	1	≈0	≈0	0.0447	0.0264	0.0264
	3	≈0	≈0	0.1341	0.0792	0.0792
	5	≈0	≈0	0.2235	0.1320	0.1320
	7	≈0	≈0	0.3129	0.1848	0.1848
CFRP	1	0.1776	-0.0092	0.0372	0.0926	0.0290
	3	0.5328	-0.0276	0.1117	0.2778	0.0869
	5	0.8880	-0.0460	0.1862	0.4630	0.1449
	7	1.2432	-0.0644	0.2606	0.6482	0.2029

† $\left(N = 2,\ scheme\ (0/90),\ a/h = 10,\ a/R_\alpha = 0.5,\ a/mR_\beta = 0.5,\ a/b = 1, and\ \ m = n = 1\right)$, while materials properties could be found in [2].

Conclusions

In the present work the elastic deformations capacity under pure bending conditions (e.g., typical reeling installation conditions) of composite ball socket pipe has been analyzed from a theoretical standpoint by means of a physically intuitive treatment. It has been shown that the proposed formulation, which partially attains some classical expressions by a different line of reasoning, is may serve as a reference in designing the composite ball socket joint pipe and improve the standards and specifications on the flexible pipes. Apart from possessing a clear physical meaning, on account of its simplicity the presented treatment seems also very suitable for developing and prototyping purposes.

Acknowledgments

The authors would like to acknowledge Universiti Teknologi PETRONAS, Malaysia for sponsoring this research work.

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