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The Laminated Composite Thermosetting Pipe

Thar M. Badri Albarody[1,a], and Zahiraniza Bt Mustaffa [1,b]

[1]Civil Engineering Department, Universiti Teknologi PETRONAS, Bandar Seri Iskandar, 31750 Tronoh, Perak, Malaysia

[a]t.albarody@ymail.com, [b]zahiraniza@petronas.com.my

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Abstract. The thermosetting pipes are eligible to be used in oil transportation where resistance to crude oil, paraffin build-up as well as ability to withstand relatively high pressures is required. Lamination design of such system could provide better strength and stability for internal and external loadings in both the circumferential and longitudinal directions. To this aim, a straightforward design and modeling of thermosetting pipe is developed via using first order shell theories. Apart from possessing an accurate operational condition, on account of its simplicity the proposed simulation seems also very suitable for further developing and prototyping purposes. Finally, it has been shown that the proposed thermosetting pipe, which partially attains some classical characteristic of both offshore and onshore pipeline by a different line of reasoning, is may serve as a reference in designing thermosetting pipe.

Introduction

Laminated Composite Thermosetting Pipe (LCTP), Fig. 1, is a system offers complete solution for offshore environment against highly corrosive fluids at various pressures, temperatures, adverse soil and weather conditions (especially in oil exploration, desalination, chemical plants, fire mains, dredging, portable water etc.)[1-3]. The chemical resistance, service temperature and the weight of such system helps reduce heavy and expensive construction cost[4, 5]. In this work, a pipe comprise an internal thermoplastic layer play as liner and a fluid-tight cover, and one or more dual-helical wounding tape stacks applied to the internal liner for absorbing axial and bending loads. The composite tape stacks are formed from a plurality of thin tape strips. All the layers are composed together to form on singular surface of the said thermosetting pipe.

Theoretical Model

Based on the laminated composite thick cylindrical shell theories [6, 7] the equations of motion could be drawn as:

$$\frac{\partial}{\partial\alpha}\mathrm{N}_{\alpha}+\frac{\partial}{\partial\beta}\mathrm{N}_{\beta\alpha}+\mathcal{F}_{\alpha}=\left(\bar{\mathrm{I}}_1\frac{\partial^2\mathrm{u}_o}{\partial t^2}+\bar{\mathrm{I}}_2\frac{\partial^2\psi_\alpha}{\partial t^2}\right),\ \frac{\partial}{\partial\beta}\mathrm{N}_{\beta}+\frac{\partial}{\partial\alpha}\mathrm{N}_{\alpha\beta}+\frac{\mathrm{Q}_\beta}{\mathrm{R}_\beta}+\mathcal{F}_{\beta}=\left(\bar{\mathrm{I}}_1\frac{\partial^2\mathrm{v}_o}{\partial t^2}+\bar{\mathrm{I}}_2\frac{\partial^2\psi_\beta}{\partial t^2}\right)$$

$$-\frac{\mathrm{N}_\beta^{\mathcal{S}}}{\mathrm{R}_\beta}+\frac{\partial}{\partial\alpha}\mathrm{Q}_\alpha+\frac{\partial}{\partial\beta}\mathrm{Q}_\beta+\mathcal{F}_n=\left(\bar{\mathrm{I}}_1\frac{\partial^2\mathrm{w}_o}{\partial t^2}\right)$$

$$\frac{\partial}{\partial\alpha}\mathrm{M}_{\alpha}+\frac{\partial}{\partial\beta}\mathrm{M}_{\beta\alpha}-\mathrm{Q}_\alpha+\mathcal{C}_{\alpha}=\left(\bar{\mathrm{I}}_2\frac{\partial^2\mathrm{u}_o}{\partial t^2}+\bar{\mathrm{I}}_3\frac{\partial^2\psi_\alpha}{\partial t^2}\right),\ \frac{\partial}{\partial\beta}\mathrm{M}_{\beta}+\frac{\partial}{\partial\alpha}\mathrm{M}_{\alpha\beta}-\mathrm{Q}_\beta+\mathcal{C}_{\beta}=\left(\bar{\mathrm{I}}_2\frac{\partial^2\mathrm{u}_o}{\partial t^2}+\bar{\mathrm{I}}_3\frac{\partial^2\psi_\beta}{\partial t^2}\right).\tag{1}$$

Having applied the Navier' solution [8-10], the equations of motion can be written in terms of displacements as $(\mathcal{K}_{ij}+\lambda^2\mathcal{M}_{ij})\{\Delta\}=\{\mathcal{F}\}$. Where $\mathcal{K}_{ij}$ is the stiffness matrix and $\mathcal{M}_{ij}$ is the mas matrix, $\{\mathcal{F}\}$ is the applied force, $\{\Delta\}^t=\left\{U_{mn},V_{mn},W_{mn},\Psi_{mn}^{\alpha},\ \Psi_{mn}^{\beta}\right\}$, and λ^2 is the eigenvalue of the problem[11, 12]. The configuration of the $\bar{\mathcal{K}}_{ij}$ terms for the SS, cross-ply and rectangular plane form is listed below

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

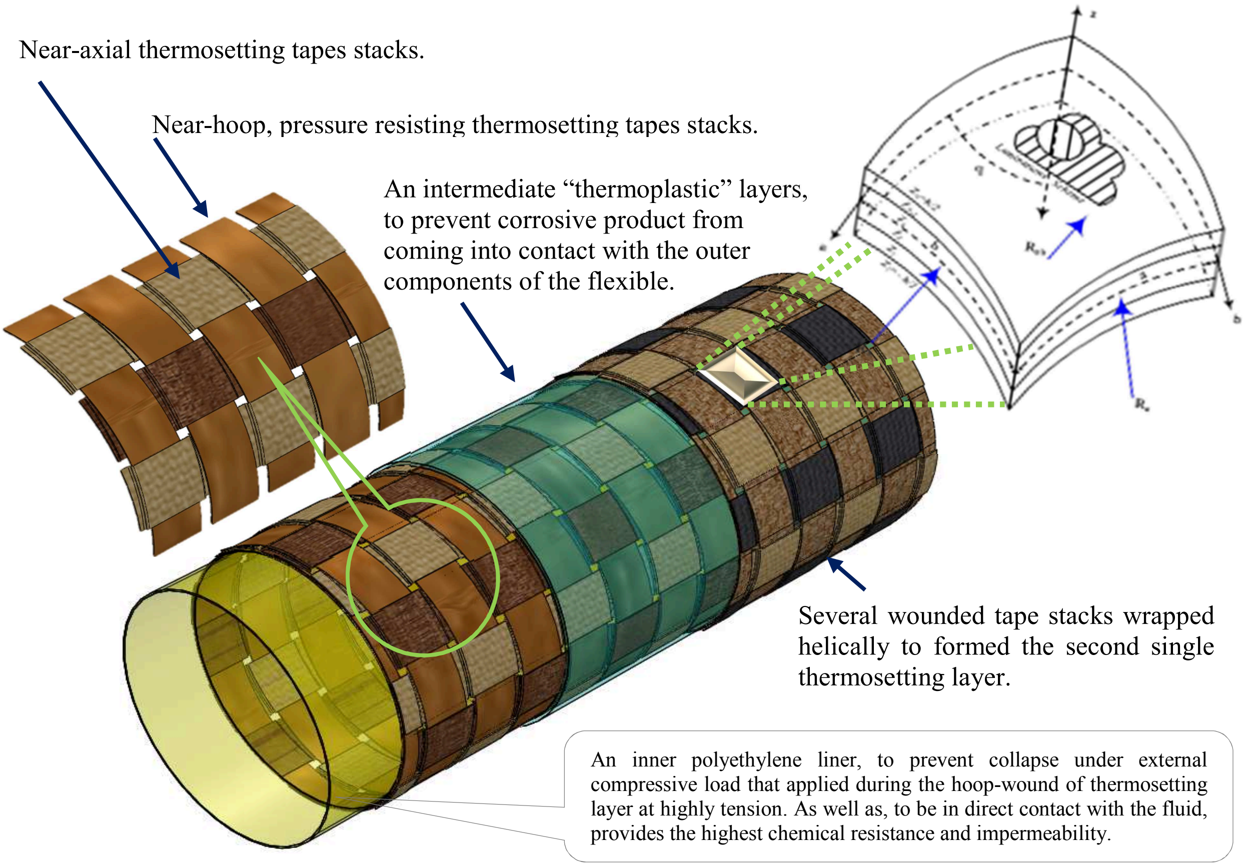

Fig. 1. Thermosetting pipe.

$$\mathcal{K}_{13}=\left(\frac{\varsigma_{12}^{1}}{R_\beta}\right)\alpha_m,\ \mathcal{K}_{23}=\left(\frac{\tilde{\varsigma}_{22}^{1}+\tilde{\varsigma}_{44}^{1}}{R_\beta}\right)\beta_n,\quad \mathcal{K}_{33}=-\tilde{\varsigma}_{44}^{1}\beta_n^2-\bar{\varsigma}_{55}^{1}\alpha_m^2-\left(\frac{\tilde{\varsigma}_{22}^{1}}{R_\beta}\right),\ \mathcal{K}_{14}=-\bar{\varsigma}_{11}^{2}\alpha_m^2-\tilde{\varsigma}_{66}^{2}\beta_n^2,$$

$$\mathcal{K}_{24}=-(\varsigma_{12}^{2}+\varsigma_{66}^{2})\alpha_m\beta_n,\ \mathcal{K}_{34}=\left(-\bar{\varsigma}_{55}^{1}+\frac{\varsigma_{12}^{2}}{R_\beta}\right)\alpha_m,\ \mathcal{K}_{44}=-\bar{\varsigma}_{55}^{1}-\bar{\varsigma}_{11}^{3}\alpha_m^2-\tilde{\varsigma}_{66}^{3}\beta_n^2,$$

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

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

The mass matrix is diagonally by $\bar{I}_1$, $\bar{I}_2$, and $\bar{I}_3$ which are the inertia terms and could defined as:

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

where Ik is the mass density of the kth layer of the shell per unit mid-surface area, and $\varsigma_{ij}^{p}\rightarrow p=1,2,3,4$; 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:

$$\underbrace{\left(\varsigma_{ij}^{1},\varsigma_{ij}^{2},\varsigma_{ij}^{3},\varsigma_{ij}^{4}\right)}_{(i,j=1,2,6)}=\sum_{k=1}^{N}\int_{h_{k-1}}^{h_k}\hat{\varsigma}_{ij}^{k}\,(1,\zeta,\zeta^2,\zeta^3)\,d\zeta,\quad \underbrace{\left(\varsigma_{ij}^{1},\varsigma_{ij}^{2},\varsigma_{ij}^{3},\varsigma_{ij}^{4}\right)}_{(i,j=4,5)}=$$

$$K_i^2\sum_{k=1}^{N}\int_{h_{k-1}}^{h_k}\hat{\varsigma}_{ij}^{k}\,(1,\zeta,\zeta^2,\zeta^3)\,d\zeta,\ \text{ and all other } \varsigma\equiv 0 \tag{3}$$

where $[\bar{*}]_{ij}^{n}=[*]_{ij}^{n}-C_o[*]_{ij}^{n+1}$ and $[\tilde{*}]_{ij}^{n}=[*]_{ij}^{n}+C_o[*]_{ij}^{n+1}$ and $\hat{\varsigma}_{ij}^{k}$ 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)[13, 14]. In addition, h_k is the distance from the mid-surface to the surface of the k^{th} layer having the farthest ζ-coordinate.

Parametric Analysis

Based on the thick laminated composite cylindrical shell theory, the transvers stress is simulated a cross the thickness of the pipe segment examining various orthotropy ratio. Fig. 2, displays that the transvers stress of laminated composite with weak orthotropy ratio could expand the pipe life. That's obvious, because the pipe properties in the hope direction almost equal to those in longitudinal direction [15-24]. Results reveal that constructing the pipe segment by composing more layers at cross ply scheme could give similar behavior to those of weak orthotropy ratio.

Conclusions

Although, the proposed flexible pipe is lighter in weight than prior art pipes it expect maintaining correct performances,particularly mechanical performances. 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 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.

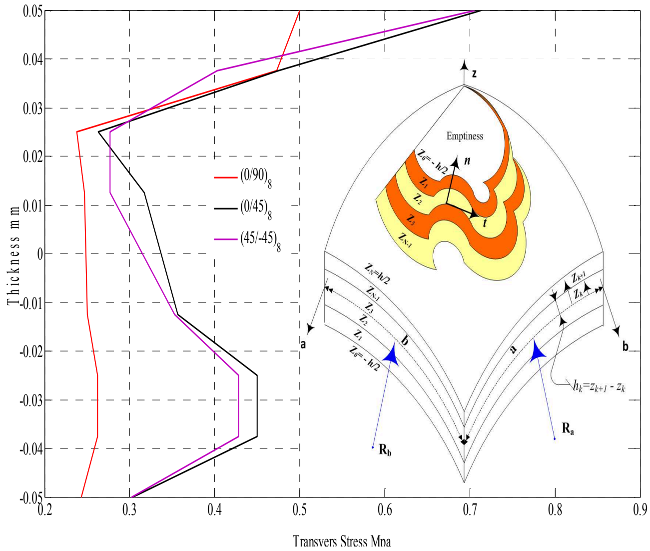

Fig. 2. The inter-laminar stresses that induced into the pipe at diffrent laminations scheme.

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