Optimum Design Of Composite Pipe By Imitating Structure Of Haversian System In Animal Bone

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**ABSTRACT:** The structure of composite pipe is similar to biological bone Haversian system. In this paper, micro model of constitutive equations of osteon was established by Donnell-Mushtali hypothesis, osteon mode was simplified, control equations for the buckling of laminated composite cylindrical shell was obtain. The composite pipe optimum has been made by imitating structure of biological bone haversian system.

**Keywords**: Composite pipe, Haversian system, Optimum design

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**I. INTRODUCTION**

The pipe of city water supply and drainage system is crucial to Millions of urban resident’s lives and health. In the past, the pipe was made of cast-iron or concrete in china, these two types pipe’s service life is short, very susceptible to be corrosion or jam ,and by trench technology to fix. At present the whole country faces a tough mission to transformate the city water supply and drainage system. For such large-scale transformation to the water supply and drainage network construction, must be used trenchless technology to avoid air pollution and traffic congestion. People expect a longer life pipe which has corrosion resistance and better integrated economic and social benefits also can be apply to trenchless technology. Under this situation the composite pipe is precisely the new high performance pipe which arises at the historic moment. Electrical networks, communication networks also need trenchless construction, composite pipe is the best option.

Composite pipe is made of two or more material, its structure is similar to biological bone Haversian system, Harvarsian system is multi-layer concentric structure, In different layer.the collagen fibers have different angle. Fig.1(a),(b). In this paper, the optimization has been made to the composite pipe which will be used for trenchless technology through the imitation of biological bone Haversian system.

![Figure 1](image)

**Figure 1** (a) Composite pipe , (b) Microstructure of the three-dimensional for compact bone.

**II. THEORETICAL ANALYSIS**

Constitutive equations of Harvarsian system :

\[\sigma_x = [(2\mu + \lambda)V_m + E_f l V_f] \varepsilon_x + [2V_m + E_f l^2 m V_f] \varepsilon_y + 2V_m \varepsilon_z + E_f l m V_f \varepsilon_y \]

\[\sigma_y = [2V_m + E_f l^2 m V_f] \varepsilon_y + [(2\mu + \lambda)V_m + E_f m V_f] \varepsilon_x + 2V_m \varepsilon_z + E_f l m V_f \varepsilon_y \]

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\[ \sigma_z = \lambda V_m \varepsilon_z + \lambda V_m \varepsilon_y + (2 \mu + \lambda) V_m \varepsilon_z \]  

(1)

\[ \tau_{xy} = E_f l \mu V_j \varepsilon_z + E\mu l^2 \mu V_j \varepsilon_y + 2(\mu V_m + E_f l \mu V_j) \gamma_{sy} \]

\[ \tau_{xz} = 2 \mu V_m \gamma_{xz} \]

Laminated composite cylindrical shell geometry equation:

\[ \{ \varepsilon \} = \begin{pmatrix} \varepsilon_x \\ \varepsilon_\theta \\ \gamma_{x\theta} \end{pmatrix} = \begin{pmatrix} \varepsilon_x^0 + zk_x \\ \varepsilon_\theta^0 + zk_\theta \\ \gamma_{x\theta}^0 + zk_{x\theta} \end{pmatrix} \]

Balance equation of laminated composite cylindrical shell

(2)

\[ \{ k \} = \begin{pmatrix} k_x \\ k_\theta \\ k_{x\theta} \end{pmatrix} = \begin{pmatrix} -w_{ss} \\ 0 \\ -2w_{ss} \end{pmatrix} \]

\[ N_{ss} + N_{s\theta} = 0 \]

\[ Q_{xz} + Q_{s\theta} - R^1 N_\theta = - (\bar{N}_x w_{ss} + \bar{N}_\theta w_{s\theta}) \]

(3)

Laminated composite cylindrical shells fundamental equations using displacement method

\[ [A_{11}(\),_{ss} + A_{66}(\),_{ss}] u_0 + [(A_{12} + A_{66}(\),_{ss}] v_0 + [R^{-1} A_{12}(\),_{ss} - B_{11}(\),_{ss}

\[ - (B_{12} + 2B_{66}(\),_{ss}] w = 0 \]

(4)

\[ [(A_{11} + A_{66}(\),_{ss}] u_0 + [A_{66}(\),_{ss} + A_{22}(\),_{ss}] v_0 + [R^{-1} A_{22}(\),_{ss} - (B_{12} + 2B_{66}(\),_{ss}

\[ - B_{22}(\),_{ss}] w = 0 \]

\[ [B_{11}(\),_{ss} + (B_{12} + 2B_{66}(\),_{ss} - R^{-1} A_{12}(\),_{ss}] u_0 + [-R^{-1} A_{22}(\),_{ss} + (B_{12} + 2B_{66}(\),_{ss}

\[ + B_{22}(\),_{ss}] v_0 + [-R^{-2} A_{22}(\) + 2R^{-1}[B_{12}(\) + B_{22}(\) - 2(D_{12} + 2D_{66}(\)

\[ - D_{11}(\),_{ss} - D_{22}(\),_{ss}] w = - (\bar{N}_x w_{ss} + \bar{N}_\theta w_{s\theta}) \]

(5)

The optimum Objective is make the max deflection of the composite pipe being minimum or volume of the composite pipe being minimum

\[ F(x_1, x_2, \ldots, x_n) \rightarrow \min \quad (i = 1, 2, \ldots) \]

Design Variable is the thickness \( T(x_1, x_2, \ldots, x_n) \), angle of fiber with principal axis \( \alpha(x_1, x_2, \ldots, x_n) \), length \( L(x_1, x_2, \ldots, x_n) \), diameter and ratio of length to diameter \( BI(x_1, x_2, \ldots, x_n) \) of the composite pipe:

\[ t_1 \leq T(x_1, x_2, \ldots, x_n) \leq t_2 \]

\[ \theta_1 \leq \alpha(x_1, x_2, \ldots, x_n) \leq \theta_2 \]

\[ l_1 \leq L(x_1, x_2, \ldots, x_n) \leq l_2 \]

\[ d_1 \leq D(x_1, x_2, \ldots, x_n) \leq d_2 \]

\[ t_1 \leq BI(x_1, x_2, \ldots, x_n) \leq t_2 \]

(6)

The constraints is earth pressure in different depth and different soil, strength conditions of composite, deformation conditions of the composite pipe and boundary conditions.

So, the optimum problem is

\[ \min F(x_1, x_2, \ldots, x_n) \]

DOI:10.9790/1813-0710010812 www.theijes.com
s.t. \[ g_u(x_1, x_2, \ldots, x_n) \leq 0 \quad (u = 1, 2, \ldots, m) \]
\[ h_v(x_1, x_2, \ldots, x_n) = 0 \quad (v = 1, 2, \ldots, p) \]

(7)

III. RESULTS AND DISCUSSION

(1) Let
D = 2.270m, T = 65mm, L / D = 3.
Working conditions:
the composite pipe was in mud underground 12m, axial force F = 7661kN, radial force P = 85032.254Pa.
The optimum objective is to make the max deflection of the composite pipe minimum, found the optimum angle of fiber with principal axis;
The initial optimum angle is: \([\pm \alpha_1, \pm \alpha_2]_4\)

![Fig. 2](image-url) The iteration process of design variables, the objective function

The initial optimum angle is: \([\pm \alpha_1, \pm \alpha_2, \pm \alpha_3]_3\)

![Fig. 3](image-url) The iteration process of design variables, the objective function

The initial optimum angle is: \([\pm \alpha_1, \pm \alpha_2, \pm \alpha_3, \pm \alpha_4]_2\)

![Fig. 4](image-url) The iteration process of design variables, the objective function

Table 1 Optimum volume for different angle of fiber with principal axis

<table>
<thead>
<tr>
<th>Angle</th>
<th>Volume</th>
<th>Angle</th>
<th>Volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>0°</td>
<td></td>
<td>90°</td>
<td></td>
</tr>
<tr>
<td>180°</td>
<td></td>
<td>270°</td>
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<tr>
<td>360°</td>
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<td>45°</td>
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<td>135°</td>
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<td>120°</td>
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</tr>
<tr>
<td>60°</td>
<td></td>
<td>180°</td>
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</table>
Before optimization & After optimization

<table>
<thead>
<tr>
<th></th>
<th>Before optimization</th>
<th>After optimization</th>
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</thead>
<tbody>
<tr>
<td>$\left[ \pm \alpha_1 \right]_{4s}$</td>
<td>$\alpha$ $[0]_s$</td>
<td>$[\pm 71.54]_s$</td>
</tr>
<tr>
<td>Volume $(m^3)$</td>
<td>0.7886</td>
<td>0.4965</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Before optimization</th>
<th>After optimization</th>
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</thead>
<tbody>
<tr>
<td>$\left[ \pm \alpha_1 \pm \alpha_2 \right]_{2s}$</td>
<td>$\alpha$ $[\pm 0 / \pm 0]_s$</td>
<td>$[\pm 65.80 / \pm 65.80]_s$</td>
</tr>
<tr>
<td>Volume $(m^3)$</td>
<td>0.7886</td>
<td>0.4559</td>
</tr>
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</table>

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<th>After optimization</th>
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</thead>
<tbody>
<tr>
<td>$\left[ \pm \alpha_1 \pm \alpha_2 \pm \alpha_3 \pm \alpha_4 \right]_i$</td>
<td>$\alpha$ $[\pm 0 / \pm 0]_i$</td>
<td>$[\pm 69.92 / \pm 39.03]_i$</td>
</tr>
<tr>
<td>Volume $(m^3)$</td>
<td>0.7886</td>
<td>0.4463</td>
</tr>
</tbody>
</table>

Figure 5 Angle of fiber with principal axis of Haversian system from different layer $^{[1]}$

From Tab.1 it can be seen that when angle of fiber with principal axis $\alpha$ is $[\pm 69.92 / \pm 39.03 / \pm 35.41 / \pm 69.88]$, the volume of the composite pipe is minimum and distributing of angle of fiber with principal axis is similar with Haversian system in Fig.5.

Table 2 Optimum max deflection in conglomerate

<table>
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<tr>
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<th>Before optimization</th>
<th>After optimization</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\left[ \pm \alpha_1 \right]_{4s}$</td>
<td>$\alpha$ $[0]_s$</td>
<td>$[\pm 62.16]_s$</td>
</tr>
<tr>
<td>Max deflection(m)</td>
<td>0.02649</td>
<td>0.00802</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
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<th>After optimization</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\left[ \pm \alpha_1 \pm \alpha_2 \right]_{2s}$</td>
<td>$\alpha$ $[\pm 0 / \pm 0]_s$</td>
<td>$[\pm 45.58 / \pm 34.36]_s$</td>
</tr>
<tr>
<td>Max deflection(m)</td>
<td>0.02647</td>
<td>0.00701</td>
</tr>
</tbody>
</table>

ACKNOWLEDGMENTS

The authors gratefully acknowledge the financial support provided by the national natural science Foundation of china(10572053)

REFERENCES


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