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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 drain 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 drain 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.

(a)   (b)

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

II. THEORETICAL ANALYSIS

Constitutive equations of Harvarsian system :

$$\sigma_x = [(2\mu+\lambda)V_m + E_f l^4 V_f]\varepsilon_x + [\lambda V_m + E_f l^2 m^2 V_f]\varepsilon_y + \lambda V_m \varepsilon_z + E_f l^3 m V_f \tau_{xy}^f$$

$$\sigma_y = [\lambda V_m + E_f l^2 m^2 V_f]\varepsilon_x + [(2\mu+\lambda)V_m + E_f m^4 V_f]\varepsilon_y + \lambda V_m \varepsilon_z + E_f l m^3 V_f \tau_{xy}^f$$

$$\begin{aligned}
&\sigma_z = \lambda V_m \varepsilon_x + \lambda V_m \varepsilon_y + (2\mu + \lambda) V_m \varepsilon_z \qquad (1)\\
&\tau_{xy} = E_f l^3 m V_f \varepsilon_x + E_f l m^3 V_f \varepsilon_y + 2(\mu V_m + E_f l^2 m^2 V_f)\gamma_{xy}\\
&\tau_{yz} = 2\mu V_m \gamma_{yz}\\
&\tau_{xz} = 2\mu V_m \gamma_{xz}
\end{aligned}$$

Laminated composite cylindrical shell geometry equation：

$$\{\varepsilon\} = \begin{Bmatrix} \varepsilon_x \\ \varepsilon_\theta \\ \gamma_{x\theta} \end{Bmatrix} = \begin{Bmatrix} \varepsilon_x^0 + z k_x \\ \varepsilon_\theta^0 + z k_\theta \\ \gamma_{x\theta}^0 + z k_{x\theta} \end{Bmatrix} \qquad \{\varepsilon^0\} = \begin{Bmatrix} \varepsilon_x^0 \\ \varepsilon_\theta^0 \\ \gamma_{x\theta}^0 \end{Bmatrix} = \begin{Bmatrix} u_0,_x \\ v_0,_s + R^{-1} w \\ v_0,_x + u_{0,s} \end{Bmatrix}$$

(2)

$$\{k\} = \begin{Bmatrix} k_x \\ k_\theta \\ k_{x\theta} \end{Bmatrix} = \begin{Bmatrix} -w,_{xx} \\ -w,_{ss} \\ -2w,_{xs} \end{Bmatrix}$$

Balance equation of laminated composite cylindrical shell

$$\begin{aligned}
&N_x,_x + N_{x\theta},_s = 0\\
&N_{x\theta},_x + N_\theta,_s = 0\\
&Q_{xz},_x + Q_{\theta z},_s - R^{-1} N_\theta = -(\overline{N}_x w,_{xx} + \overline{N}_\theta w,_{\theta\theta}) \qquad (3)\\
&M_x,_x + M_{x\theta},_s - Q_{xz} = 0\\
&M_{\theta x},_x + M_\theta,_s - Q_{\theta z} = 0
\end{aligned}$$

Laminated composite cylindrical shells fundamental equations using displacement method

$$\begin{aligned}
&[\mathrm{A}_{11}(\ ),_{xx} + A_{66}(\ ),_{ss}]u_0 + [(A_{12} + A_{66})(\ ),_{xs}]v_0 + [R^{-1}A_{12}(\ ),_x - B_{11}(\ ),_{xxx}\\
&-(B_{12} + 2B_{66})(\ ),_{xss}]w = 0\\
&[(A_{12} + A_{66})(\ ),_{xs}]u_0 + [A_{66}(\ ),_{xx} + A_{22}(\ ),_{ss}]v_0 + [R^{-1}A_{22}(\ ),_s - (B_{12} + 2B_{66})(\ ),_{xxs}\\
&-B_{22}(\ ),_{sss}]w = 0 \qquad (4)\\
&[B_{11}(\ ),_{xxx} + (B_{12} + 2B_{66})(\ ),_{xss} - R^{-1}A_{12}(\ ),_x]u_0 + [-R^{-1}A_{22}(\ ),_s + (B_{12} + 2B_{66})(\ ),_{xxs}\\
&+B_{22}(\ ),_{sss}]v_0 + \{-R^{-2}A_{22}(\ ) + 2R^{-1}[B_{12}(\ ),_{xx} + B_{22}(\ ),_{ss}] - 2(D_{12} + 2D_{66})(\ ),_{xxss}\\
&-D_{11}(\ ),_{xxxx} - D_{22}(\ ),_{ssss}\}w = -(\overline{N}_x w,_{xx} + \overline{N}_\theta w,_{\theta\theta})
\end{aligned}$$

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

$$F_i(x_1, x_2, ..., x_n) \to \min \qquad (i = 1, 2, \cdots) \qquad (5)$$

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

$$\left.\begin{aligned}
&t_1 \le T(x_1, x_2 \ldots x_n) \le t_2\\
&\theta_1 \le \alpha(x_1, x_2 \ldots x_n) \le \theta_2\\
&l_1 \le L(x_1, x_2 \ldots x_n) \le l_2\\
&d_1 \le D(x_1, x_2 \ldots x_n) \le d_2\\
&t_1 \le BI(x_1, x_2 \ldots x_n) \le t_2
\end{aligned}\right\} \qquad (6)$$

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[3] is

$$\min F(x_1, x_2, ..., x_n)$$

$$s.t.\quad g_u(x_1, x_2, ..., x_n) \le 0 \qquad (u = 1, 2, \cdots, m)$$
$$h_v(x_1, x_2, ..., x_n) = 0 \qquad (v = 1, 2, \cdots, p) \tag{7}$$

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 make the max deflection of the composite pipe being minimum ,found the optimum angle of fiber with principal axis ;
The initial optimum angle is: $[\pm\alpha_1{}^\circ]_{4s}$

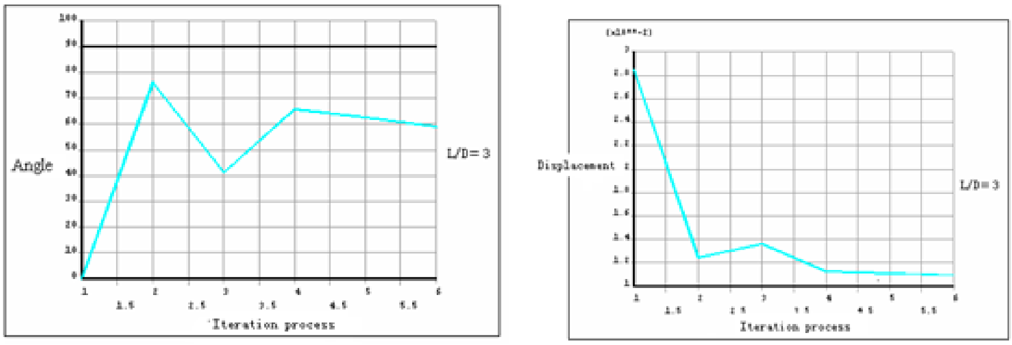

Fig.2 The iteration process of design variables, the objective function

The initial optimum angle is: $[\pm\alpha_1 / \pm\alpha_2]_{2s}$

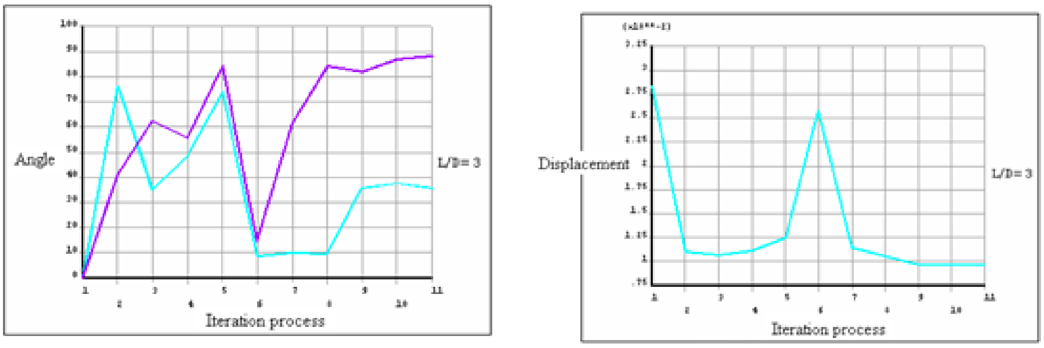

Fig.3 The iteration process of design variables, the objective function

The initial optimum angle is: $[\pm\alpha_1 / \pm\alpha_2 / \pm\alpha_3 / \pm\alpha_4]_s$

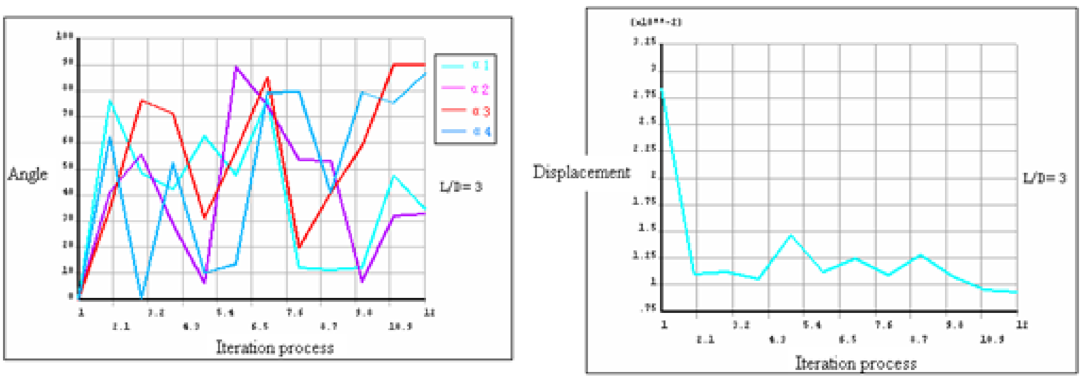

Fig.4 The iteration process of design variables, the objective function

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

		Before optimization	**After optimization**
$[\pm\alpha_1]_{4s}$	α	$[\pm 0]_{4s}$	$[\pm 71.54]_{4s}$
	Volume （m^3）	0.7886	0.4965
$[\pm\alpha_1/\pm\alpha_2]_{2s}$	α	$[\pm 0/\pm 0]_{2s}$	$[\pm 65.80/\pm 65.80]_{2s}$
	Volume （m^3）	0.7886	0.4559
$[\pm\alpha_1/\pm\alpha_2/\pm\alpha_3/\pm\alpha_4]_s$	α	$[\pm 0/\pm 0/\pm 0/\pm 0]_s$	$[\pm 69.92/\pm 39.03/\pm 35.41/\pm 69.88]_s$
	Volume	0.7886	0.4463

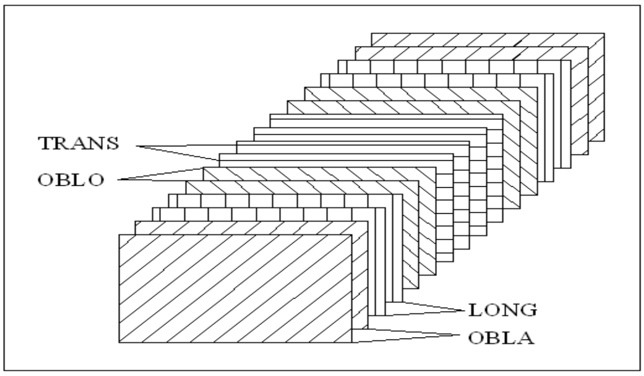

Figure5 Angle of fiber with principal axis of Haversian system from different layer[1]

From Tab.1 it can be seen that when angle of fiber with principal axis is $[\pm 69.92/\pm 39.03/\pm 35.41/\pm 69.88]_s$,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

		Before optimization	**After optimization**
$[\pm\alpha_1]_{4s}$	α	$[\pm 0]_{4s}$	$[\pm 62.16]_{4s}$
	Max deflection(m)	0.02649	0.00802
$[\pm\alpha_1/\pm\alpha_2]_{2s}$	α	$[\pm 0/\pm 0]_{2s}$	$[\pm 90.00/\pm 41.31]_{2s}$
	Max deflection(m)	0.02647	0.00805
$[\pm\alpha_1/\pm\alpha_2/\pm\alpha_3/\pm\alpha_4]_s$	α	$[\pm 0/\pm 0/\pm 0/\pm 0]_s$	$[\pm 45.58/\pm 34.36/\pm 90.00/\pm 90.00]_s$
	Max deflection(m)	0.02647	0.00701

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