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Experiment for Bending Analysis of 3-phase Composite Plate in Ship Structure

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Abstract. Composite is a material composed of two or more component materials to obtain better properties. 3-phase composite is usually added with reinforced fibers and particles. This report presents an experimental study on the bending of some 3-phase composite plates for Vietnam's shipbuilding industry. The studied composite is made of polyester matrix, glass fiber and titanium dioxide particle (TiO_2). The numerical study, in which the interaction between the matrix and particle is taken into account, shows good agreement with the experiment.

1. Introduction

To improve both the mechanical and physical properties, composite can be reinforced simultaneously with both fibers and particles, thus 3-phase composite appears.

The bending problem of anisotropic plate and shell is studied in [1,2]. The bending of composite is studied in [2,3]. In [4], we investigate the bending problem for 3-phase composite, taking into account the shear effect, and in [5] we take into account the creep effect.

Recently, the present authors have published some experiments to determine the elastic modules for 3-phase composite with different volume ratio of fiber and particle. Our purpose in this paper is to continue the experiments, for the bending of 3-phase composite plates used in Vietnam's shipbuilding. The material is made of polyester matrix, reinforced by glass fibers and titanium dioxide particles. The formulas used for the calculation are from [6-8] and [4-5,9].

2. Prepare the samples

The samples' dimension is 500mmx300mm. It is made of 6 plies, the stack sequence is [$0^o/+45^o/-45^o/+45^o/-45^o/90^o$]. The plate's thickness is 5.5 mm. The material's components are AKAVINA polyester, glass fiber imported from Korea, and titanium dioxide particle imported from Australia.

The test is done with test machine SANS following method BS EN ISO 527-1: 1997. Room temperature is ($20^0C\pm5^0C$), humidity is 65%±20%, the samples are manufactured according to

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standard TCVN 6282:2008 [10]. The experiments were done in the Laboratory of the Shipbuilding Science and Technology Institute - Nha Trang University.

Fig. 1. Bending test for 3-phase composite plate.

3. Deflection equation

For orthotropic plates material, the stress-strain relationship is [1-3]:

$$\begin{cases} \sigma_{11} = A_{11}\varepsilon_{11} + A_{12}\varepsilon_{22} \\ \sigma_{22} = A_{22}\varepsilon_{22} + A_{12}\varepsilon_{11} \\ \sigma_{66} = A_{66}\varepsilon_{66} \\ \sigma_{44} = A_{44}\varepsilon_{44} \\ \sigma_{55} = A_{55}\varepsilon_{55} \end{cases} \quad (1)$$

Here

$$A_{11} = \frac{E_{11}}{1-\nu_{12}\nu_{21}};\; A_{22} = \frac{E_{22}}{1-\nu_{12}\nu_{21}};\; A_{12} = \frac{E_{11}\nu_{21}}{1-\nu_{12}\nu_{21}} = \frac{E_{22}\nu_{12}}{1-\nu_{12}\nu_{21}};\; A_{66} = G_{12} \quad (2)$$

Our purpose is to determine the deflection for 3-phase composite plate. As we mentioned above, the deflection equation for orthotropic plates is described in [1-3,11]. When shear strain is taken into account, the deflection equation is expressed by three differential equations [4]:

$$\begin{cases} \dfrac{\partial j}{\partial x} + \dfrac{\partial y}{\partial y} = -\dfrac{z}{I_2(h)} \\ D_x \dfrac{\partial^3 w}{\partial x^3} + \left(D_1 + 2D_{x,y}\right)\dfrac{\partial^3 w}{\partial x \partial y^2} - \dfrac{12}{h^3} I_1\left[\dfrac{D_y}{A_{55}}\dfrac{\partial^2 j}{\partial x^2} + \dfrac{D_{xy}}{A_{55}}\dfrac{\partial^2 j}{\partial y^2} + \dfrac{\left(D_1 + D_{xy}\right)}{A_{44}}\dfrac{\partial^2 j}{\partial x \partial y}\right] + I_2 j = 0 \\ D_y \dfrac{\partial^3 w}{\partial y^3} + \left(D_1 + 2D_{x,y}\right)\dfrac{\partial^3 w}{\partial x^2 \partial y} - \dfrac{12}{h^3} I_1\left[\dfrac{D_y}{A_{44}}\dfrac{\partial^2 y}{\partial y^2} + \dfrac{D_{xy}}{A_{44}}\dfrac{\partial^2 y}{\partial x^2} + \dfrac{\left(D_1 + D_{xy}\right)}{A_{55}}\dfrac{\partial^2 y}{\partial x \partial y}\right] + I_2 y = 0 \end{cases} \quad (3)$$

The set of equation (3) is the basic set to determine the plate's deflection when shear strain is taken into account. The coefficients A_{11}, A_{22}, A_{12}, A_{66}, A_{44}, A_{55} are used to determine D_{ij} in (3). These coefficients can be calculated from the elastic modules of the material. Note that with the ratio between the plate's length and thickness equals 500/5,5=91, our plates are considered to be very thin and shear effect can be neglected, thus we can use the deflection equation mentioned in [1,2,11] which is not repeated here.

4. Determine the elastic modules for 3-phase composite plate

The elastic modules for 3-phase composite are calculated step by step by 2-phase model as in [5,6,8]. We also carried out the experiments for 3-phase composite's elastic modules [9].

After determining ($\bar{G},\bar{K}$) or ($\bar{E},\bar{n}$) for effective matrix, the elastic modules for 3-phase composite can be calculated as below [6,7]:

$$E_{11} = \xi_a E_a + (1-\xi_a)\bar{E} + \frac{8\bar{G}\xi_a(1-\xi_a)(\nu_a - \bar{\nu})}{2-\xi_a + \bar{x}\xi_a + (1-\xi_a)(x_a-1)\dfrac{\bar{G}}{G_a}}$$

$$E_{22} = \left\{ \frac{\nu_{21}^2}{E_{11}} + \frac{1}{8\bar{G}} \left[\frac{2(1-\xi_a)(\bar{\chi}-1) + (\chi_a-1)(\bar{\chi}-1+2\xi_a)\dfrac{\bar{G}}{G_a}}{2-\xi_a+\bar{\chi}\xi_a+(1-\xi_a)(\chi_a-1)\dfrac{\bar{G}}{G_a}} + 2\frac{\bar{\chi}(1-\xi_a)+(1+\xi_a\bar{\chi})\dfrac{\bar{G}}{G_a}}{\bar{\chi}+\xi_a+(1-\xi_a)\dfrac{\bar{G}}{G_a}} \right] \right\}^{-1}$$

$$\nu_{21} = \bar{\nu} - \frac{(\bar{\chi}+1)(\bar{\nu}-\nu_a)\xi_a}{2-\xi_a+\bar{\chi}\xi_a+(1-\xi_a)(\chi_a-1)\dfrac{\bar{G}}{G_a}}; G_{12} = \bar{G}\frac{1+\xi_a+(1-\xi_a)\dfrac{\bar{G}}{G_a}}{1-\xi_a+(1+\xi_a)\dfrac{\bar{G}}{G_a}};$$

$$G_{23} = \bar{G}\frac{\bar{\chi}+\xi_a+(1-\xi_a)\dfrac{\bar{G}}{G_a}}{(1-\xi_a)\bar{\chi}+(1+\bar{\chi}\xi_a)\dfrac{\bar{G}}{G_a}} \tag{4}$$

Here $G_a = \dfrac{0.5E_a}{(1+\mu_a)}$; $G_c = \dfrac{0.5E_c}{(1+\mu_c)}$; $\bar{E} = \dfrac{9\bar{K}\bar{G}}{3\bar{K}+\bar{G}}$; $\bar{\nu} = \dfrac{3\bar{K}-2\bar{G}}{6\bar{K}-2\bar{G}}$; $\bar{x} = 3-4\bar{n}$ (5)

and $\bar{G},\bar{K}$ are the elastic modules of the effective matrix

$$\bar{G} = G_m\frac{1-\xi_c(7-5\nu_m)H}{1+\xi_c(8-10\nu_m)H}; \quad \bar{K} = K_m\frac{1+4\xi_c G_m L(3K_m)^{-1}}{1-4\xi_c G_m L(3K_m)^{-1}} \tag{6}$$

Here $L = \dfrac{K_c - K_m}{K_c + \dfrac{4G_m}{3}}$; $H = \dfrac{G_m/G_c - 1}{8-10\nu_m+(7-5\nu_m)\dfrac{G_m}{G_c}}$ (7)

5. Experiment result

In the experiment, the two shorter edges of the plate are clamped, while the two longer edges are free. The concentrated force is increased with time (Figure 1). There are two set of samples: set A (20% fiber and 10% particle) and set B (20% fiber and 20% particle).

The test result for maximum deflection at the plate's center is given in Table 1.

Table 1. Comparison between analysis and experiment for bending deflection

3-phase composite	Concentrate force / Deflection (mm)	1kN	3kN	6kN	10kN	Ultimate deflection
$10\%TiO_2$ + 20%W800 + 70% AKAVINA polyester (sample type A)	Experiment*	7,6	14,2	20,8	32,4	34,3
	Analysis	8,1	15,3	22,2	34,2	-
	Error %	6,57	7,75	6,73	5,56	-
$20\%TiO_2$ + 20%W800 + 60% AKAVINA polyester (sample type B)	Experiment*	6,0	12,3	19,2	29,0	33,0
	Analysis	6,5	13,4	21,0	31,6	-
	Error %	8,33	8,94	9,30	8,96	-

*Note: *is the average result after 5 tests for one sample type.*

From the result in Table 1, we can come to a conclusion: adding fiber and particle can decrease the plate's deflection. When the added material's volume ratio is increased, the deflection is decreased. Moreover, compare to increasing the particle's volume ratio, increasing the fiber's volume ratio can decrease the deflection faster.

6. Conclusion

In this paper we report the experiments for bending problem of 3 phase composite made of polyester matrix, glass fiber and titanium dioxide particle.

The experiment result shows that the particle's volume ratio doesn't affect the deflection much, while fiber and the plate's thickness affect it better.

Comparison between analysis and experiment show good agreement.

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