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EXPERIMENTAL STUDY ON MECHANICAL PROPERTIES FOR A THREE - PHASE POLYMER COMPOSITE REINFORCED BY GLASS FIBERS AND TITANIUM OXIDE PARTICLES

Nguyen Dinh Duc[1], **Dinh Khac Minh**[2]
[1] *University of Engineering and Technology*
[2] *Shipbuilding Science and Technology Institute*

Abstract. Nowadays, composite materials are applied in many fields. The physico - mechanical properties of the material can be improved by adding reinforced fibers and particles. Many scientists pay attention to the calculation for elastic modules of three - phase composite materials. This report presents the experimental results for some elastic modules of three - phase polymer composite reinforced with glass fibers and titanium oxide particles of different volume ratios. A comparison between experimental and theoretical results shows good agreement.

Key words: Three - phase composite (polyester, glass fiber, titanium oxide), elastic modulus, experimental.

1. INTRODUCTION

Composite material consists of two or more component materials to obtain a new material with better properties. The components are matrix material and filled materials (reinforced or additive). The function of matrix material is to unite the components, assure the resistance to heat and physicochemical loads, while the filled components are used to improve the mechanical properties (stiffness and strength) of the composite [5, 6, 7, 10].

The reinforced components used usually are fibers and particles. Fibers can increase the stiffness, while particles can decrease the fracture, plastic strain and improve the water and gas proof ability of the composite. Thus, the addition of fibers and particles can make composite become more perfect, to satisfy more and more requirements of modern technology.

Having advantages such as: light weight, resistance to heat and environmental loads, composite materials are widely applied in many fields: from industry, construction, machine - building, transportation to aerospace engineering and medical engineering. In Vietnam, within the past ten years, many researches and applications for composite have been done, especially for polymer composites. The properties of polymer composites is indicated in [5, 6, 9]. In ship building industry, guard ship, passenger ship, fishing vessel of small and medium sizes are mainly made of composite materials. To improve the water - proof, fire

- proof, corrosion - proof and crack resistant properties of the material, particles often be added to the matrix besides fibers. This leads to the appearance of three - phase composite which having three phases: polymer matrix, reinforced fibers and particles. To deal with the structural problems, we need to know the mechanical behavior of the material, which means firstly determining the elastic modules of the composite (Fig. 1).

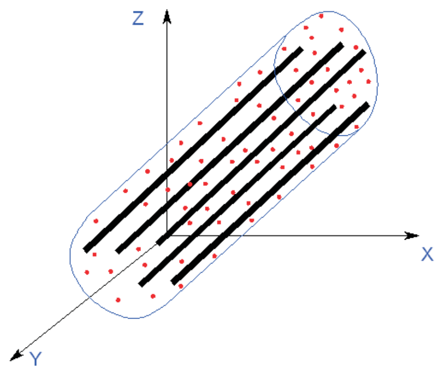

Fig. 1. Model of three - phase composite with reinforced fiber and particle

2. DETERMINE THE ELASTIC MODULES OF THREE - PHASE COMPOSITE

There are two main methods for determining the elastic modules of three - phase composite material: experimental and analytical methods. The advantage of experimental method is that it can provide the exact result for the material's modules. However, since three - phase composite is a multi - component material, the experiment can not illustrate the effect that the component phases have on the overall mechanical properties of the material. The analytical method often uses a mechanical model of a three-phase composite material reinforced with fibers (normally in cylindrical shape) and particles (in spherical shape) to calculate the material's elastic modules. It has a principal advantage: the modules are explicitly determined from the properties and aspect ratios of the component phase. When these factors are changed, new composite is obtained and their physicomechanical properties can be predicted, thus this method provides the foundation for optimal design of new material and structure.

Another method is the inductive method, in which the predicted formulas for the elastic modules are derived based on a large number of experiments. Such formulas are often suggested by the scientists in experimental physics. But with the appearance of the third phase, the experiments and the prediction for the variation of the elastic modules from the component phases' parameters become very complex. So far we have only seen publications [10] using this method for two - phase composites (matrix and reinforced particles).

In our previous reports, the elastic modules of three - phase composites are estimated using two theoretical models of the two - phase composite consecutively: $\mathrm{nD}_m = \mathrm{O}_m + \mathrm{nD}$

[3, 4, 12]. This paper considers three - phase composite reinforced with particles and unidirectional fibers, so the problem's model will be: $1D_m = O_m + 1D$.

The researches on determining the elastic modules for composite material with reinforced particles are reported in [1, 2, 10, 11, 12]. In our papers [11, 12], the interaction between matrix and particles is taken into account. Firstly, the modules of the effective matrix O_m which called "effective modules" are calculated. In this step, the effective matrix consists of the original matrix and particles, it is considered to be homogeneous, isotropic and have two elastic modules. The next step is estimating the elastic modules for a composite material consists of the effective matrix and unidirectional reinforced fibers.

Thus, the result for the three - phase composite problem depends much on the models for the two - phase composite problem and it can have different accuracy for different composites.

For composite reinforced with particles, several methods for determining elastic modules have been proposed [1, 2, 10, 11, 12]. In this research, we chose the method which takes into account the interaction between matrix and particle [2, 12].

There are also researches on determining the elastic modules for composite reinforced by unidirectional fibers [1, 7, 8, 11]. This type of material is often considered orthotropic with 5 elastic modules [1, 7]. The most modern reports with two independent approaches by Pobedrya B.E. [8] and Vanin G.A. [11] have calculated the sixth modulus of this material, and their results show good agreement to each other.

Assume that all the component phases (matrix, fiber and particle) are homogeneous and isotropic, we will use E_m, ν_m, E_a, ν_a, E_c, ν_c to denote Young modulus and Poisson ratio for matrix, fiber and particle, respectively. According to [2], we can obtain the modules for the effective composite as below:

$$\bar{G} = G_m \frac{1 - \xi_c (7 - 5\nu_m) H}{1 + \xi_c (8 - 10\nu_m) H} \tag{1}$$

$$\bar{K} = K_m \frac{1 + 4\xi_c G_m L (3K_m)^{-1}}{1 - 4\xi_c G_m L (3K_m)^{-1}} \tag{2}$$

here,

$$L = \frac{K_c - K_m}{K_c + \dfrac{4G_m}{3}}, \quad H = \frac{G_m/G_c - 1}{8 - 10\nu_m + (7 - 5\nu_m)\dfrac{G_m}{G_c}}. \tag{3}$$

$\bar{E}, \bar{\nu}$ can be calculate from $(\bar{G}, \bar{K})$ as below

$$\bar{E} = \frac{9\bar{K}\bar{G}}{3\bar{K} + \bar{G}}, \quad \bar{\nu} = \frac{3\bar{K} - 2\bar{G}}{6\bar{K} - 2\bar{G}} \tag{4}$$

The modules for three - phase composite reinforced with unidirectional fiber are chosen to be calculated using Vanin's formulas [11]:

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

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

$$G_{12} = \bar{G}\frac{1 + \xi_a + (1-\xi_a)\dfrac{\bar{G}}{G_a}}{1 - \xi_a + (1+\xi_a)\dfrac{\bar{G}}{G_a}}, \quad G_{23} = \bar{G}\frac{\overline{\chi} + \xi_a + (1-\xi_a)\dfrac{\bar{G}}{G_a}}{(1-\xi_a)\overline{\chi} + (1+\overline{\chi}\xi_a)\dfrac{\bar{G}}{G_a}}, \tag{5}$$

$$\frac{\nu_{23}}{E_{22}} = -\frac{\nu_{21}^2}{E_{11}} + \frac{1}{8\bar{G}} \left[2\frac{(1-\xi_a)\bar{x} + (1+\xi_a\bar{x})\dfrac{\bar{G}}{G_a}}{\bar{x} + \xi_a + (1-\xi_a)\dfrac{\bar{G}}{G_a}} - \right.$$
$$\left. - \frac{2(1-\xi_a)(\bar{x}-1) + (x_a - 1)(\bar{x} - 1 + 2\xi_a)\dfrac{\bar{G}}{G_a}}{2 - \xi_a + \bar{x}\xi_a + (1-\xi_a)(x_a - 1)\dfrac{\bar{G}}{G_a}} \right],$$

$$\nu_{21} = \bar{\nu} - \frac{(\overline{\chi}+1)(\bar{\nu} - \nu_a)\xi_a}{2 - \xi_a + \overline{\chi}\xi_a + (1-\xi_a)(\chi_a - 1)\frac{\bar{G}}{G_a}}.$$

in which $\bar{x} = 3 - 4\bar{\nu}$.

One of the goals of this research is to do the experiments to verify the results for the modules E_{11}, E_{22}, G_{12} of three - phase composite materials calculated using the formulas (5) above.

3. EXPERIMENT AND RESULT

To verify Young modules for three - phase composite, we tested the samples made of polyester AKAVINA (made in Vietnam), fibers (made in Korea) and titanium oxide (made in Australia) with the properties as in Table 1.

The experiments were done on HOUNSFEILD H50K-S tester (Fig. 2) using BS EN ISO 527-1: 1997 method. Room's temperature was (20±5^{0}C), humidity was 65%±20%. The samples were made according to Vietnamese standard code: TCVN 6282:2008 [13]. The dimension of the samples is given in Fig. 3. The experiments were done at the Laboratory of Shipbuilding Technology Institute, Nha Trang University.

Table 1. Properties of component phases for the three - phase composite

Component phase	**Young modulus E**	**Poisson ratio ν**
Matrix polyester AKAVINA (Vietnam)	1,43 Gpa	0.345
Glass fiber (Korea)	22 Gpa	0.24
Titanium oxide TiO_2 (Australia)	5,58 Gpa	0.20

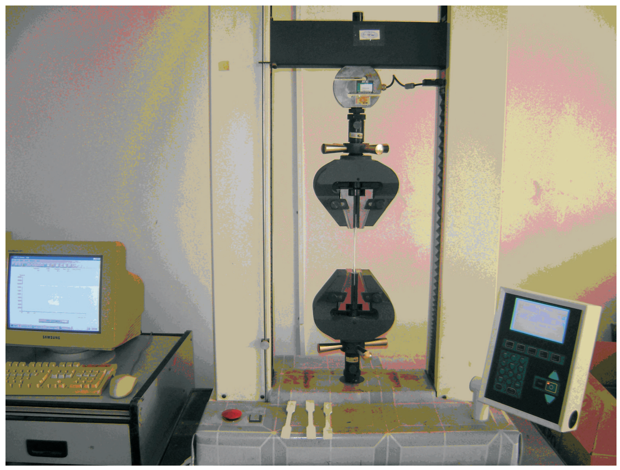

Fig. 2. HOUNSFEILD H50K-S Tester

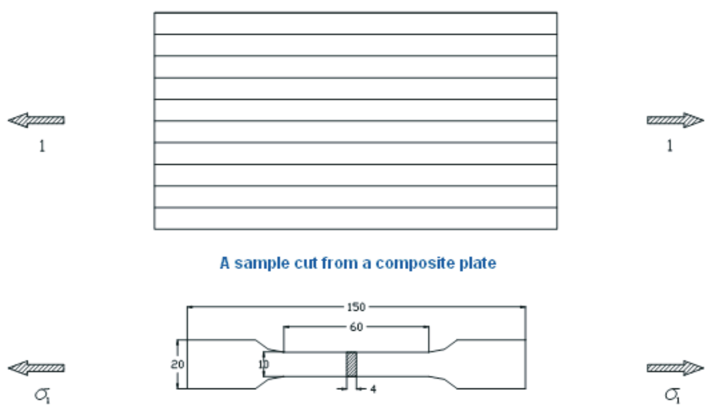

Fig. 3. Dimension of three - phase composite sample

Totally more than 60 samples were tested for 8 different cases of fibers and particle's volume ratios (as in the first column of Table 2). Tensile test was done for estimating E_{11}, E_{22} and in 45 degree direction for estimating E_{45} and G_{12}. The experiments' results is given in Table 2.

According to the tests' results, fiber has much effect on improving Young modulus, while particle has much effect on shear modulus.

Table 2. Experiment results for three - phase composite's elastic modules

	Elastic Modulus			
Composite	$\mathbf{E_{45}}$	$\mathbf{E_1}$	$\mathbf{E_2}$	$\mathbf{G_{12}}$
20%TiO$_2$ + 15%W800 + 65% polyester	3012.36	4548.25	2750.58	742.07
	2996	4673.56	2678.5	720.138
	2977.7	4695.67	2670.26	700.504
	2879.5	4825.34	2740.79	700.18
20%TiO$_2$ + 20%W800 + 60% polyester	3768.89	6208.64	2828.56	719.518
	3752.2	6330.28	2931.42	715.799
	3527.23	6347.5	2815.96	713.146
	3340.08	6191.18	2923.98	712.51
20%TiO$_2$ + 25%W800 + 55% polyester	3725.65	7270.8	3018.02	701.868
	4001.73	6981	3158.63	702.952
	3791.82	6959.8	3377.35	705.731
	3582.3	6911	3045.76	701.31
	3889.3	6956	3072.91	702.432
20%TiO$_2$ + 30%W800 + 50% polyester	4330	7658.5	3230.54	677.701
	4275	7580.4	3267.62	697.542
	4106.81	7604	3254.59	700.201
30%TiO$_2$ + 15%W800 + 55% polyester	2046.11	4725	2939.3	818.577
	2467.39	4774	2932.81	800.125
	2614.2	5073	3033.59	844.859
	2244.17	5231	2997.34	801.6411
30%TiO$_2$ + 20%W800 + 50% polyester	4025	6341	3278.59	807.049
	3819.55	6423	3146.34	801.252
	3738.52	6582.5	3178.75	803.382
30%TiO$_2$ + 25%W800 + 45% polyester	3661.27	6875	3425.62	799.966
	3992.65	6465	3462.25	805.524
	3623.84	7012	3659.15	791.349
	3707.86	6609	3547.13	786.753
30%TiO$_2$ + 30%W800 + 40% polyester	4342.58	8230	3655.53	768.72
	4229.44	8308	3708.33	761.511
	4090	8092	3602.52	775.503
	4111.5	8792	3670.48	801.844

The comparison between experimental results (average values from Table 2) with theoretical result (formulas (5)) is shown in Table 3.

4. CONCLUSION

From Table 3, we can obtain that the theoretical analysis and experiment have good agreement for elastic modules of three - phase composite made of polyester matrix, glass fibers and titanium oxide particles. This conclusion allows us to apply the algorithm and formulas proposed in this research for estimating the elastic modules and other structure and material problems using three - phase composite.

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Table 3. Comparison between experiment and analysis

Composite		E_1	E_2	G_{12}
20%TiO$_2$ + 15%W800 + 65% polyester	Experimental	4685.70	2709.95	715.72
	Theoretical	4787.5	2791.0	673.8
	Error	2.1%	2.9%	6.2%
20%TiO$_2$ + 20%W800 + 60% polyester	Experimental	6269.4	2874.98	715.24
	Theoretical	5781.7	2996.7	666.9
	Error	8.4%	4.1%	7.3%
20%TiO$_2$ + 25%W800 + 55% polyester	Experimental	7015.72	3152.55	708.65
	Theoretical	6778.4	3221.7	659.3
	Error	3.5%	2.2%	7.5%
20%TiO$_2$ + 30%W800 + 50% polyester	Experimental	7614.3	3250.91	691.8
	Theoretical	7777.5	3468.9	650.7
	Error	2.1%	6.7%	6.3%
30%TiO2 + 15%W800 + 55% polyester	Experimental	4950.75	2975.76	816.30
	Theoretical	4980.5	3091.6	766.5
	Error	0.6%	3.7%	6.5%
30%TiO$_2$ + 20%W800 + 50% polyester	Experimental	6348.6	3201.22	803.9
	Theoretical	5962.1	3310.4	757.7
	Error	6.5%	3.4%	6.1%
30%TiO$_2$ + 25%W800 + 45% polyester	Experimental	6717.75	3523.54	795.90
	Theoretical	6946.3	3549.1	747.9
	Error	3.4%	0.7%	6.4%
30%TiO$_2$ + 30%W800 + 40% polyester	Experimental	8355.5	3659.22	776.89
	Theoretical	7933.1	3810.6	737.0
	Error	5.3%	4.1%	5.4%

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