

Theoretical and experimental study on determining the elastic coefficients of grain-reinforced composites

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Abstract — Currently, there are two main methods to determine the elastic modulus of grain-reinforced composite materials: experiment and theoretical method. The advantage of the experimental method is to determine the elastic modulus for the composite exactly, but this method does not reflect the influence of the component material phases on the mechanical properties of the composite in general. The analytical method can solve this problem. In this paper, the author studies how to determine the elastic coefficients of grain-reinforced composites by both theory and experiment. The results of this paper give us reliable values of elastic coefficients to serve for the calculation of structures made of grain-reinforced composite.

I. INTRODUCTION

Composite materials are popular due to the following advantages: Flexible combining with other materials to increase durability and reduce cost; Lightweight, durable, resistant to corrosive environments, inert to the environment, not corroded by seawater and oysters; Easy to apply, easy to repair, easy to shape, has high surface gloss and aesthetics, needs simple construction equipment; Long life more than 20 years.

Besides the above advantages, composite materials still have disadvantages such as permeability, flammability, easy abrasion, low hardness, and low impact strength. To improve these disadvantages, besides the fiber reinforcement, particles are often added to the polymer matrix. Particles are added to the polymer matrix to produce a mixture of higher density and improved mechanical properties. In general, the particle increases the elastic modulus and the shear modulus, and many theories have been developed to explain this effect.

In this study, the elastic coefficients of the grain-reinforced composite were determined both theoretically and

experimentally. The theoretical method is built on the basis of a mechanical problem model, which introduces a two-phase composite model with particle reinforcement, (particles are considered to be spherical). The advantage of this method is that the elastic coefficients are determined depending on the properties and distribution ratio of the component materials. Changing these parameters, new composites with different physical-mechanical properties can be obtained, and their values can also be calculated in advance. This is the basis for calculating the new material optimization design [4,5]. The experimental method was conducted with the aim of verifying the theoretical results found. Then, the elastic coefficients are used as input data for the strength, stiffness, and stability problems of structures made of grain-reinforced composite materials.

II. DETERMINATION OF THE ELASTIC COEFFICIENTS FOR THE GRAIN-REINFORCED COMPOSITES

For two-phase polymer composite materials, the determination of the elastic coefficients is how to calculate

the elastic coefficients of the material, which is expressed through the mechanical - physical parameters and the geometric distribution. of the component materials. Considering a two-phase composite consisting of the initial matrix phase and particles, such a composite is considered to be homogeneous, isotropic, and has two elastic coefficients [2,3]. The determination of the elastic coefficients for composites filled with spherical particles is determined, taking into account the interaction between the particles and the matrix. The elastic coefficients of the grain-reinforced composite are now called hypothetical composites.

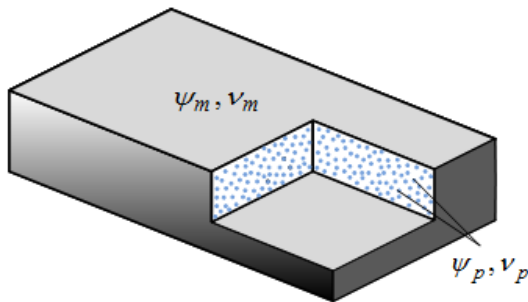


Fig. 1: Polymer composite model with grain-reinforcement

Assuming the components of the composite are all homogeneous and isotropic, then $E_m, G_m, K_m, \nu_m, \psi_m; E_p, G_p, K_p, \nu_p, \psi_p$ are denoted by the modulus of elasticity, modulus of elasticity of shear, modulus of volume deformation, Poisson's coefficient, and composition ratio (by volume) of the matrix and particles, respectively. From here on, the quantities related to the matrix will have the m -index; relative to the particle is the p -index. According to [6], the elastic modulus of the assumed composite as follows:

$$\bar{E} = \frac{9\bar{K}\bar{G}}{3\bar{K} + \bar{G}}; \quad \bar{\nu} = \frac{3\bar{K} - 2\bar{G}}{6\bar{K} + 2\bar{G}} \quad (1)$$

where:

$$\bar{G} = G_m \frac{1 - \psi_p (7 - 5\nu_m) H}{1 + \psi_p (8 - 10\nu_m) H}; \quad (2)$$

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

with:

$$L = \frac{K_p - K_m}{K_p + \frac{4G_m}{3}}; \quad H = \frac{\frac{G_m}{G_p} - 1}{8 - 10\nu_m + (7 - 5\nu_m) \frac{G_m}{G_p}} \quad (3)$$

$$G_i = \frac{E_i}{2(1 + \nu_i)}; \quad K_i = \frac{E_i}{3(1 - 2\nu_i)} \quad (i = m, p)$$

III. NUMERICAL CALCULATIONS AND EXPERIMENTS

3.1. Numerical calculations

Considering the influence of particles on the physical and mechanical properties of two-phase composite materials according to the above algorithm, considering two-phase composite materials with the characteristics in Table 1.

Table 1. Parameters of composite component materials

Material	Modulus of elasticity (GPa)	Poisson's coefficient
Glass beads reinforced polyester composite materials		
Polyester AKA	$E_m = 1.43$	$\nu_m = 0.345$
Reinforced glass beads	$E_p = 22,2$	$\nu_p = 0.24$
Glass beads reinforced Epoxy composite materials		
epoxy	$E_m = 4.81$	$\nu_m = 0.3$
Reinforced glass beads	$E_p = 22,2$	$\nu_p = 0.24$

Substitute the values in Table 1 into the formulas (1) (3) to determine the elastic coefficients of two-phase composite materials as in Table 2.

Table 2. Calculation results of elastic coefficients of two-phase composite materials

	Modulus of elasticity CPS (\bar{E} [GPa])		Poisson's coefficient CPS ($\bar{\nu}$)	
	Polyester - glass beads	epoxy - glass beads	polyester - glass beads	Epoxy - glass beads
0.2	2.037	6.203	0.311	0.278
0.3	2.436	7.052	0.291	0.266
0.4	2.930	8.033	0.268	0.253
0.5	3.557	9.183	0.240	0.239
0.6	4.379	10.54	0.205	0.223
0.7	5.505	12.192	0.160	0.204

The graph shows the relationship between the ratio of material composition and the elastic coefficients of the two-phase composite.

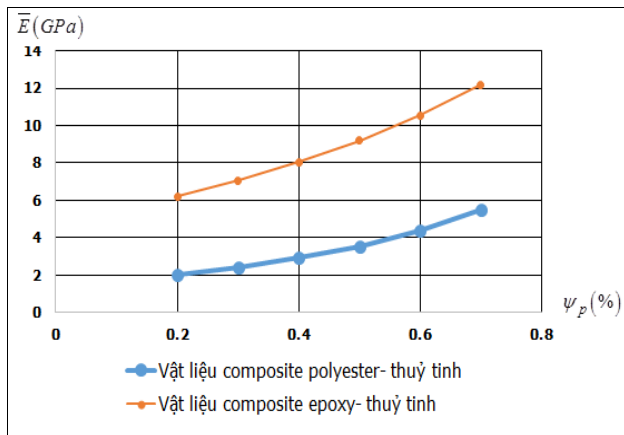


Fig.2: Relationship between \bar{E} and ψ_p

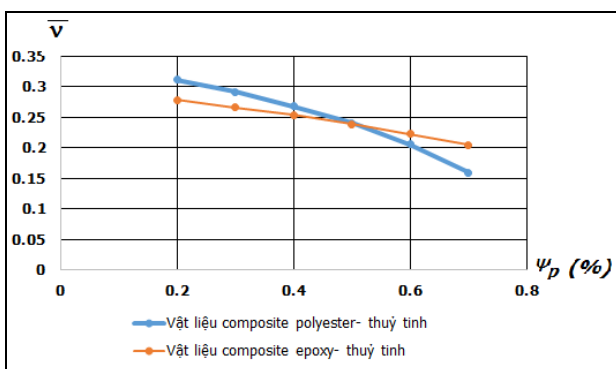


Fig.3: Relationship between \bar{v} and ψ_p

From Fig.2 and 3 we observe that with the composite material shown above, changing the reinforcement structure significantly changes the elastic modulus and the porosity coefficient of the composite. Thus, we can calculate for three-phase composite materials. When in the base material additional filler particles are added (these particles may be of the same type or different from the fibrous material). Or it can also be understood as the material consisting of the base and the filler particles with the addition of a third phase, the reinforcement fibers. The inclusion of fibers as reinforcement for the composite increases the shear modulus, increases the stiffness and strength of the material.

3.2. Experiment

The goal of experiments is to verify the theoretical results that have just been found. Component materials for making samples are list in Table 1. Specifications for making samples according to combinations: 1) 20% glass beads +80% polyester; 2) 30% glass beads +70% polyester; 3) 40% glass beads +60% polyester; 4) 50% glass beads +50% polyester; 60% glass beads +70% polyester; 70% glass beads +30% polyester and the

manufacturing process of two-phase composite materials is as follows: - Weigh and measure the proportion of component materials. First, mix the glass beads into the polyester resin in the form of a paste according to the specified ratio. Using a stirrer with a speed of 750 rpm, stir within 24 hours for the glass to be evenly mixed into the resin. - Start processing the sample, proceed to solidify. To avoid the creation of air bubbles, an iron roller is usually used to roll from the top of the plate to the end of the sample plate. The test sample is processed according to standards BS EN ISO 527-4: 1997 [1] as Fig. 4.

Equipment for tractors, universal compressor MTS-810 Landmark (USA). These experimental machines produced since 2010. The MTS-810 Landmark is the most modern universal energy system in Vietnam at the present time, the machine operates on the principle of electronic-hydraulic combination. It is capable of tests: tensile, compression, bending, shear, and creep tests under static and dynamic loads, under normal or high-temperature conditions up to 1200°C. In the test process, the strain response to the load is carried out through the mechanical-electrical extensometers and signal processors integrated into the machine. This vitality system has been calibrated and certified by the Bureau of Standards, Metrology, and Laboratory Equipment.

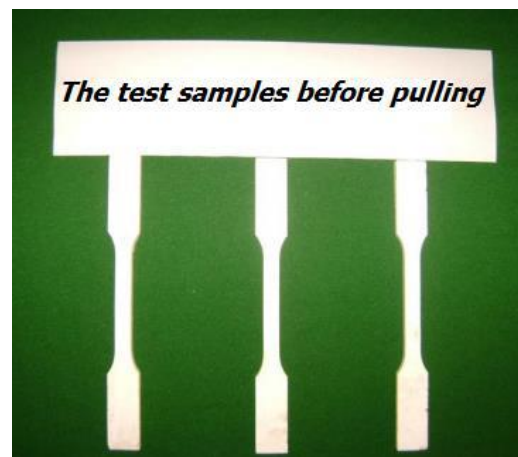


Fig. 4: Sample used for the experiment

The basic parameters of the MTS-810 Landmark system are as follows:

Maximum load: 500kN;

Maximum distance between 2 sides of the sample: 2108mm;

Distance between two columns: 762mm;

Maximum test temperature range: 1200°C;

Loads: Static and dynamic (pulse: sawtooth, triangle, square and sinusoidal variable load);

The maximum longitudinal oscillation frequency of clamping head: 12Hz.

Standard of extensometer: 10mm, 20mm, 50mm.

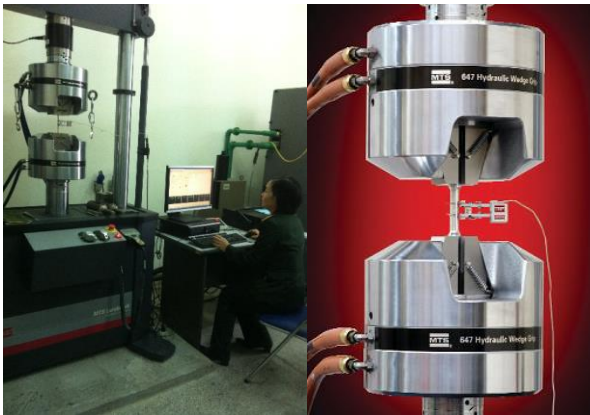


Fig.5: Experiment to determine the mechanical and physical properties of the grain-reinforced composite materials

The results of the theoretical calculation according to the formula (1)-(3) compared with the experiment are presented in Table 3.

Table 3. Results of comparison between theory and experiment of glass-grain reinforced polyester-based composites

Composite		Results	
		\bar{E} (GPa)	$\bar{\nu}$
20% glass beads +80% polyester resin	Experiment	2.356	0.308
	Theory	2.037	0.311
	Error	13,53%	1,05%
30% glass beads +70% polyester resin	Experiment	2.592	0.283
	Theory	2.436	0.291
	Error	6,0%	2,89%
40% glass beads +60% polyester resin	Experiment	2.764	0.256
	Theory	2.930	0.268
	Error	5,68%	4,62%
50% glass beads +50% polyester resin	Experiment	3.297	0.245
	Theory	3.557	0.24
	Error	7,32%	1,78%
60% glass beads +40% polyester resin	Experiment	4.125	0.215
	Theory	4.379	0.205
	Error	5,81%	4,21%
70% glass beads +30%	Experiment	4.525	0.207
	Theory	5.505	0.160

polyester resin	Error	17,81%	22,69%
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Similarly, the theoretical and experimental results with epoxy resin materials and reinforced glass beads according table 4 as follows:

Table 4. Results of comparison between theory and experiment of glass-reinforced epoxy-based composites

Composite		Results	
		\bar{E} (GPa)	$\bar{\nu}$
20% glass beads +80% epoxy resin	Experiment	6.835	0.265
	Theory	6.203	0.278
	Error	9,23%	4,74%
30% glass beads +70% epoxy resin	Experiment	7.485	0.263
	Theory	7.052	0.266
	Error	5,78%	1,1%
40% glass beads +60% epoxy resin	Experiment	7.693	0.25
	Theory	8.033	0.253
	Error	4,24%	1,37%
50% glass beads +50% epoxy resin	Experiment	8.495	0,229
	Theory	9.183	0.239
	Error	7,49%	4,26%
60% glass beads +40% epoxy resin	Experiment	9.885	0,225
	Theory	10.546	0.223
	Error	6,27%	0,82%
70% glass beads +30% epoxy resin	Experiment	10.834	0,215
	Theory	12.192	0.204
	Error	11,13%	4,8%

Tables 3 and 4 show that: In the actual construction of composite materials, a good ratio between the reinforcement and the foundation is about 30% ÷ 60%, which is reasonable, when the particle volume is less than 30% and greater than 60%, the error is between theory and experiment increased significantly. From that, an important parameter can be derived that characterizes the structural distribution which is the volume coefficient (volume of aggregates) / volume of the whole composite), this coefficient is usually from 0.3-0.6 – that is, the reinforcement composition is usually 30% and not more than 60% of the composite volume. Especially when the distribution of reinforcement occupies more than 70% of the volume, they are too close together, between them arise interactions leading to stress concentration, and reduce the strength of the material.

IV. CONCLUSION

In this article, two approaches, theoretical and experimental, have been presented to determine the elastic coefficients of grain-reinforced composite materials. Both the theoretical and experimental results are relatively coincidental. The article gives a reasonable parameter that characterizes the structural distribution as the volume coefficient from 0.3-0.6. The results of this paper give reliable elastic modulus to serve for the calculation of strength, stiffness, and stability for structures made of grain-reinforced composite.

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