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ULTRASONIC NON-DESTRUCTIVE ASSESMENT OF ELASTIC PROPERTIES OF PARTICLE REINFORCED POLYMERIC COMPOSITE MATERIALS

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ABSTRACT

The paper aims to present the experimental data retrieved after ultrasonic non-destructive testing on metallic particle reinforced polymeric composite materials. The particles' size (µm), volume fraction as well as the matrix material (different types of polymeric materials – e.g. epoxy, vinyl epoxy, etc.) has their influence on the overall elastic characteristics of the composite material. On what extent and compared with several theoretical models will be the topics under focus in this paper.

Keywords: particle, polymer, composite, ultrasonics, properties.

1. INTRODUCTION

Interest in particle reinforced composite materials has expanded lately as these multi-phase mixtures often provide outstanding overall material properties. Consequently, these composite materials had gained numerous applications that exploit their mechanical/electrical properties. These applications include static shielding of delicate electronic components, radar absorption, alternatives for insulating/heating systems or other types of applications from aeronautics and automotive industries or dental restoration, etc..

In such circumstances, it is useful to be able to predict the bulk behaviour of a composite material from knowledge of the intrinsic properties of its constituents, since this ability is a fundamental requirement in the development, characterization, and optimization processes of a novel material.

There is mathematical equivalence in the calculation of a number of physical parameters including elastic coefficients, electrical and thermal conductivity, resistance, impedance and magnetic permeability of particle reinforced composite structures having one or multiple layers [1-4]. This fact has been partly responsible for wide contributions on the subject, as researchers in many fields have addressed the problem of calculating the properties of this class of materials. Hence, the papers cited by this article are related with the research and focus interest of the author, as a natural consequence of developing the subject of its PhD, as well as with the trend in the domain.

The herein paper focuses on metallic particle (Fe particles on different sizes) embedded on different polymeric matrix material (epoxy vinyl ester, polyester, epoxy, etc.) with the aim of retrieving some of the overall composite material properties, such as elastic coefficients.

2. THEORETICAL ASPECTS

Over the past 50 years or so, a huge number of experimental and theoretical papers having as subject the mechanical properties of particle reinforced composite materials have been published. However, the understanding of the relationship between the macroscopic mechanical behaviour and the micro-structural properties (volume fraction of particles, size distribution, etc.) is far from satisfactory. A number of models have been proposed to describe the mechanical, thermal and electrical behaviour of particle reinforced composite materials. These models vary substantially in assumptions, applicability, accuracy, complexity and completeness. In spite of this no one equation has been found to adequately represent all the systems.

From all theoretical models derived under a micromechanics approach, the **Hashin-Strikman** seems to give a closer “representation” to the elastic coefficients of the particle reinforced composite materials, regardless the spherical inclusions having or not variations from the ideal shape, etc. Consequently, the following stands for (m – matrix, p – particles, V_p – particles’ volume fraction):

Bulk modulus:

$$K = \frac{\left(K_m + \frac{4}{3} \cdot G_m\right) \cdot \left(K_p + \frac{4}{3} \cdot G_p\right)}{\left(1 - V_p\right) \cdot \left(K_p + \frac{4}{3} \cdot G_p\right) + V_p \cdot \left(K_m + \frac{4}{3} \cdot G_m\right)} - \frac{4}{3} \cdot G_m; \tag{1}$$

respectively, the shear modulus:

$$G = \frac{\left(G_m + A\right) \cdot \left(G_p + A\right)}{\left(1 - V_p\right) \cdot G_p + V_p \cdot G_m + A} - A, \tag{2}$$

where: $A = \frac{G_m}{6} \cdot \frac{9 \cdot K_m + 8 \cdot G_m}{K_m + 2 \cdot G_m}$ (3)

For isotropic materials, the Young modulus is related to shear and bulk moduli as:

$$E = \frac{9 \cdot K \cdot G}{3 \cdot K + G}; \tag{4}$$

and Poisson ratio can be written like:

$$\nu = \frac{1.5 \cdot K - G}{3 \cdot K + G}. \tag{5}$$

In figure 1 is being plotted the theoretical values of Young modulus for Fe (technical pure) particles embedded into an epoxy matrix with respect to particles’ volume fraction [1, 3], whereas in figure 2 is being plotted the theoretical values corresponding to the longitudinal ultrasonic velocity vs. particles’ volume fraction for the same types of particles – Fe - embedded on different types of polymeric materials (see table 1).

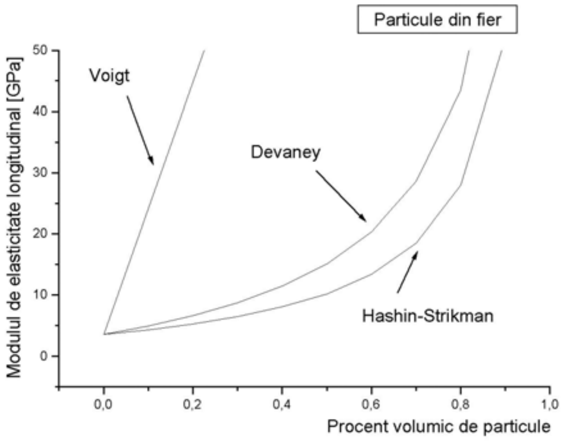


Figure 1. Young modulus vs. particle volume fraction - different theoretical models

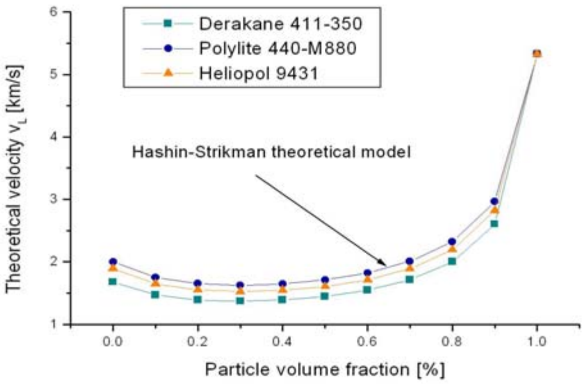


Figure 2. Longitudinal velocity vs. particle volume fraction – different matrix materials, Fe particles

3. EXPERIMENTAL RESEARCH. DISCUSSIONS

The experimental research aimed a non-destructive ultrasonic testing of the samples manufactured using a self-made technology, specially developed to obtain particle reinforced polymeric composite materials. The materials used for composite manufacturing and some of their particulates are being listed on table 1. The elastic coefficient evaluation from ultrasonic measurements represents the first step in the attempt of this polymeric composite materials class characterization.

The experimental set-up used had the well-known classical configuration based on contact principles of the transducers with the sample's surfaces and came from **Krautkramer-Branson**.

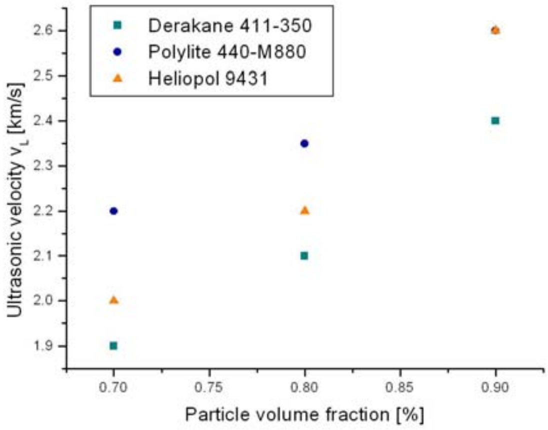


Figure 3. Experimental ultrasonic velocity – 1 MHz (Fe particles – same dimens., different matrix mat.)

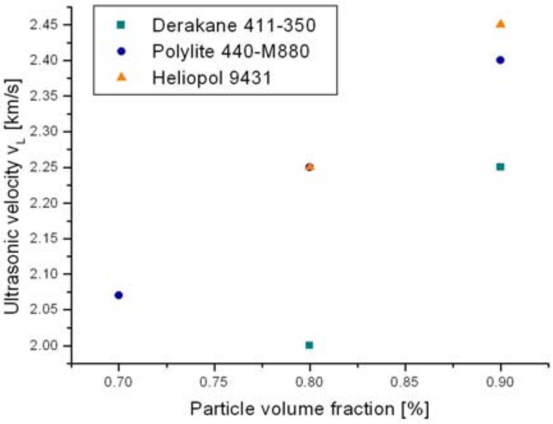
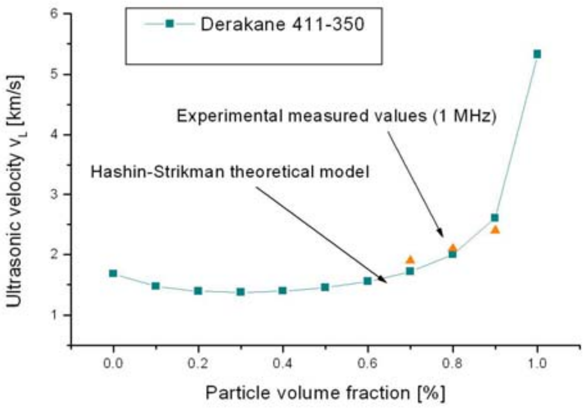
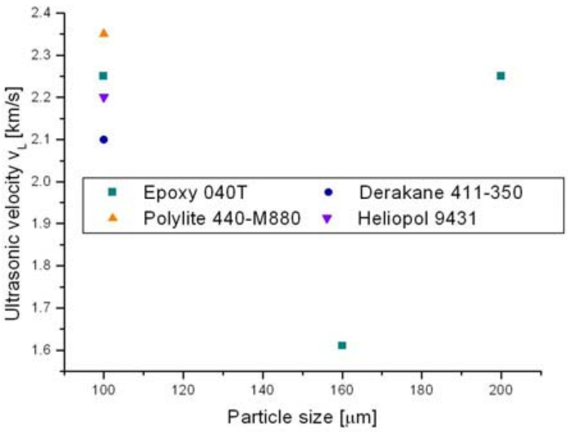


Figure 4. Experimental ultrasonic velocity – 2 MHz (Fe particles – same dimens., different matrix mat.)

The measurements aimed at the longitudinal velocity retrieval of the ultrasonic pulses through the composite samples, at different frequencies of the ultrasonic transducer excitations (1 and 2 MHz). The values obtained were used for elastic coefficients retrieval. Relations giving the connection between the velocity and elastic coefficients can be found elsewhere in the literature (see [1] and [3]).

The experimental values were plotted in figures 3 and 4, compared with the theoretical ones – as was represented in figure 5. In figure 6 was represented some of the experimental results (at 1 MHz frequency) obtained for ultrasonic velocity measurements on different composite samples made from technical pure Fe particles having different dimension sizes (200, 160 and 100 μm) embedded into different polymer matrices. As can be observed, for few samples we were not able to retrieve a value of the ultrasonic velocity.





Figures 5. Theorerical vs. experimental values 100 μm Fe, vinyl ester epoxy matrix – 1 MHz

Figure 6. Experimental values – long. velocity – 1 MHz different particle dimensions., different matrix material

Tabel 1 – Particle and matrix materials mechanical properties

Filler	*Material*:	*Particle dimensions:*	*Chemical composition*				*Density* *$[g/cm^3]$*
			C	Si	Mn	P	
	Technical pure Fe	100 μm	0.02	0.05	0.20	0.02	2.8 – 3.1
		160 μm	0.08	0.05	0.20	0.01	3.3 – 3.6
		200 μm	0.02	0.05	0.15	0.02	2.5 – 2.8
Matrix	*Material*:	*Young modulus [GPa]*	*Poisson ratio*				*Density* *$[g/cm^3]$*
	Derakane 411-350 epoxy vinyl ester resin	3.2	0.35				1.14
	Polylite 440-M880 polyester resin	4.6	0.31				1.15
	Heliopol 9431 polyester resin	4.0	0.32				1.12

4. CONCLUDING REMARKS

Several self-made polymeric composite samples having technical pure iron fillers were subjected to ultrasonic nondestructive testing with the aim of properties assessment. As can be seen from the plotted graphs:

- the measured values are closer to the Hashin-Strikman theoretical model;
- for different particle volume fraction but the same experimental conditions (the same value of ultrasonic frequency) there is a "approximate" linear variation on the measured value (ultrasonic velocity);
- for the same particles' dimensions the polymer matrix is the only influencing factor on the overall measured values; even there is the case of a polymer matrix from the same class (e.g. Heliopol and Polylite are polyester resins) the behavior are completely different.

The aforementioned ones can be exploited to develop new multifunctional composite materials having or aiming to have improved mechanical/electrical/thermal properties depending on the application areas. In order to attempt such approach, special care need to be applied on the manufacturing technology, devices and influencing factors (e.g. polymerization conditions, pressure, working temperature, etc.) and material selection and properties (e.g. particle degree of purity, size, etc.).

5. REFERENCES

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