The Effect of PVC Powder content on the Elastic Moduli and Acoustic Impedance of Epoxy Composites

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Abstract

The primary purpose of the present research was to study the effect of polyvinyl chloride (PVC) powder content on ultrasonic wave velocity in PVC/Epoxy composites. The second part is concerned with the relations of dynamic elastic moduli with the ultrasonic wave velocities, to determine how ultrasonic waves can affect them.

Experimental data have been obtained using the sonic viewer (model -5217 A) device to generate two types of waves, longitudinal waves of frequency 63 kHz and transverse waves of frequency 33 kHz and to measure the transit time required for those waves to travel through individual sample.

The experimental results have shown that the propagation of the ultrasonic velocity increases directly with PVC content in the tested specimens, due to the changes in the dynamical properties that were investigated from the calculated values of the elastic moduli of the composites.

The influence of PVC content on the acoustical impedance I of the medium was also investigated.

Keywords

Polymer composite
dynamic moduli

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دراسة تأثير أضافة مسحوق PVC على معاملات المرونة والممانعة الصوتية لمتراكبات الايبوكسي

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الخلاصة:

الهدف من اجراء البحث هو دراسة تأثير اضافة مسحوق PVC على سرعة الموجات فوق الصوتية لمتراكبات PVC/Epoxy . ثم ايجاد معاملات المرونة من العلافات التي تربط هذه المعاملات بسرعة الموجات الصوتية في الوسط.

استخدم جهاز sonic viewer (model -5217 A) لتوليد نوعين من الموجات. طولية بتردد 63 kHz وأخرى مستعرضة بتردد 33 kHz وكذلك قياس الزمن اللازم لمرور الموجات فوق الصوتية خلال العينة.

أظهرت نتائج الفحص ان سرعة انتقال الموجات فوق الصوتية خلال المتراكبات تزداد بزياة نسب المسحوق نتيجة لتغير معاملات المرونة. كذلك أظهرت نتائج الفحص زيادة في قيم الممانعة الصوتية بزياة نسب اضافة المسحوق بسبب زيادة الكثافة.

Introduction

During working period, components change their properties and characteristics, these changes are by rule of a degrading character. Usually surface changes precede inner degradation processes, when degradation occurs in a dispersive way within the element's volume a classical inspection of a structure's condition may not reveal any dangerous conditions. Therefore, there is a need of searching non-destructive methods of investigation of the degradation degree [1].

Many different nondestructive evaluation (NDE) techniques can be used to recognize the materials properties, these techniques include such things as various ultrasonic methods, x-ray imaging, eddy current methods, magnetic particle inspection, fluorescent dye infiltration, and so on. Some of these techniques, e.g. x-rays, involve health hazards, others, e.g. eddy current and magnetic particle methods, work only on specific types of materials, dye infiltration, should not be considered to be nondestructive, because it leaves a foreign material inside the tested materials[2].

In the present work, the materials properties were recognized by measuring the dynamic moduli using ultrasound techniques.

In the field of ultrasonic testing, ultrasound's physical nature as a mechanical wave is used. Parameters that may constitute diagnostic characteristics include propagation velocity of Ultrasonic waves, test (direct transition method) was used to study the dynamical properties[3,4].

In ultrasound techniques sinusoidal disturbance is applied to a sample and the resulting behavior is measured as a function of time and frequency. Tensile, shear or bulk stresses are common.

Similarly ultrasound shear or longitudinal waves may be employed to characterize the mechanical properties at higher frequencies. However, shear waves have the limitation that they do not propagate in liquids or very soft gel type materials and it is difficult to achieve good coupling especially at higher temperatures.

The propagation speed of waves depends on the elastic properties and density of the materials. When the applied stress to the surface is removed, the strain condition in the medium start to propagate as an elastic wave. Inside a homogeneous body there are two types of waves that can be generated. The first type of waves is variously called longitudinal, compressional or-P wave, the motion for these waves is to and fro in the direction of propagation. They correspond to ordinary sound waves .The second wave type, where the motion of the particles is at right angles to the propagation direction is called transverse, shear or S-wave. At the contact surface between two media there are also other types of waves, these waves for example Rayleigh waves and Love waves, travel close to the contacts between the media . For the Rayleigh waves the particle motion is in a vertical plane and elliptical and retrograde with respect to the propagation direction. The Love waves may exist when there is a low-velocity layer underlain by a medium with a higher velocity. The wave motion is perpendicular to the propagation direction of the waves and in plane parallel to the contact surface.

The velocities of longitudinal and transverse waves, designated V_p and V_s respectively, are expressed in terms of elastic moduli as follows[5]:

$$\mathbf{V_p} = \sqrt{\frac{\lambda + 2\mu}{\rho}} = \sqrt{\frac{K + (4/3)\mu}{\rho}}$$

$$= \sqrt{\frac{E(1-\sigma)}{\rho(1+\sigma)(1-2\sigma)}} \quad \text{..........} (1)$$

$$V_s = \sqrt{\frac{\mu}{\rho}} = \sqrt{\frac{E}{\rho}\frac{1}{2(1+\sigma)}} \quad \text{..........} (2)$$

$$\lambda = V_p \rho \_ 2\mu \quad \text{........................}(3)$$

$$\mu = V_s^2 \rho \quad \text{................................}(4)$$

$$K = (3\lambda + 2\mu) \quad \text{.........................}(5)$$

$$E = 2\mu(1-\sigma) \text{...........................}(6)$$

$$\sigma = \frac{1-2(\frac{V_s}{V_p})^2}{2-2(\frac{V_s}{V_p}\}^2} \quad \text{........................}(7)$$

$$I = \rho V_p \quad \text{................................}(8)$$

Where

λ= Lame's constant

μ= (shear modulus)

ρ= the density of the sample

K= Bulk modulus

E= Young' modulus

σ= Poisson's ratio

I=acoustic impedance

Equations (1) and (2) show that the velocity of the transverse waves V_s is lower than that of longitudinal waves V_p .It can also be seen that for a fluid the velocity is equal to zero since the rigidity μ is zero. Transverse waves can not propagate through fluids. Consequence of this the transverse waves are less affected than the longitudinal waves.

Experimental work

Materials and specimens preparation

Test specimens of PVC/Epoxy composites were prepared of Epoxy resin (EP10 Conbextra) supplied by Fostoc Company with the hardener aliphatic amine (Hy 956) as a matrix and PVC powder as filler, with variation of PVC powder content (5%,10% , 15% and 20% weight percentage) by conventional hand lay-up method, using parallelogram mold of dimensions (4x4x10)cm^3 under ambient conditions(~30ºC).

Measurements

The propagated ultrasonic wave velocities (longitudinal waves V_L and transverse waves V_T) through the specimens were measured using sonic viewer (model-5217A), the function of the device is to generate longitudinal and transverse waves and to measure their arrival time.

The device consists of electronic pulse generator (trigger – pulse),transmitter which converts the electrical pulses into mechanical pulses that propagate through the sample, receiver which converts the mechanical pulses to electrical pulses, amplifier used to amplify the relatively low output voltage from the receiver, oscilloscope which displays the output voltage on a screen, a coupling medium of thin gel was applied on the transmitter-sample and the receiver-sample interfaces to prevent waves attenuation by air.

Results and discussion

Compressive velocity V_p and shear velocity V_s were calculated from the arrival time according to equations (9)and (10) and were listed in table (1).

$$V_p = L / T_P \quad \text{..................}(٩)$$

$$V_s = D / T_s \quad \text{..................}(١٠)$$

V_p=compressive pulse velocity (longitudinal velocity)

V_s =shear pulse velocity (transverse velocity)

T_P = average time of compressive pulse to transverse the distance L

T_s = average time of compressive pulse to transverse the distance D

L = the length of the sample

D = the width of the sample

Table (1) Variation of compressive and shear Ultrasonic waves velocities (V_P,V_S)with PVC content

No.	ρ [g/cm^3]	Weight % of PVC	V_p [m/s]	V_s [m/s]
1	1.3	0	3110	690
2	1.37	5 %	3540	842
3	1.57	10 %	3700	925
4	1.63	15 %	4870	1316
5	1.65	20 %	5230	1564

Comparing the values of ultrasonic wave velocities with PVC content in the investigated specimens, it became clear that these two properties are directly related as illustrates in Fig.(2).The results show that in general the ultrasonic velocity increases with the increasing of PVC content, since the wave propagation in the polymeric medium depends on the motion transition between the adjacent chains through the cross-links, adding more filler particles that take place between the polymeric chains decreases the cross-links and facilitate the chains vibration (waves propagation).

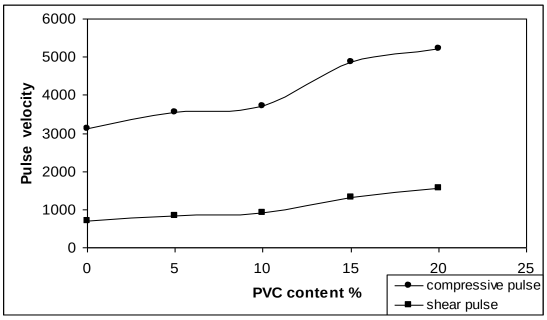

Fig.(1) Variation of ultrasonic wave velocities with PVC content in PVC /Epoxy composites

The obtained values of waves speed of the two types Tp, and T_S were used to calculate the elastic moduli shear modulus μ, bulk modulus K, Poisson ratio σ, modulus of elasticity E and acoustical impedance I using equations (3-8) [1] as were presented in tables (2-6).

Table (2) Variation of shear modulus μ values with PVC content in PVC /Epoxy composites

No.	Weight% of PVC	μ [GPa]
1	0	0.62
2	5 %	0.97
3	10 %	1.34
4	15 %	2.14
5	20 %	4

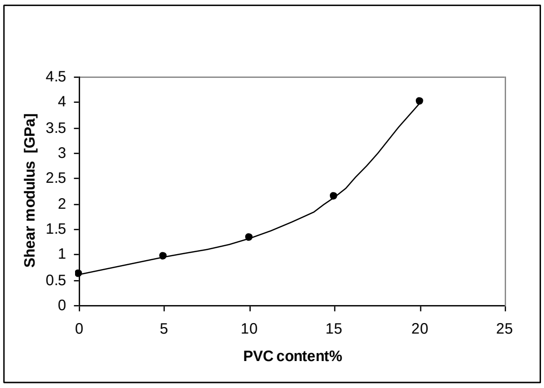

Fig.(2) Variation of shear modulus with PVC content in PVC /Epoxy composites

Table (3) Variation of Bulk K modulus values with PVC content in PVC /Epoxy composites

No.	Weight % of PVC	K [GPa]
1	0	.2
2	5 %	1.2
3	10 %	1
4	15 %	3
5	20 %	4

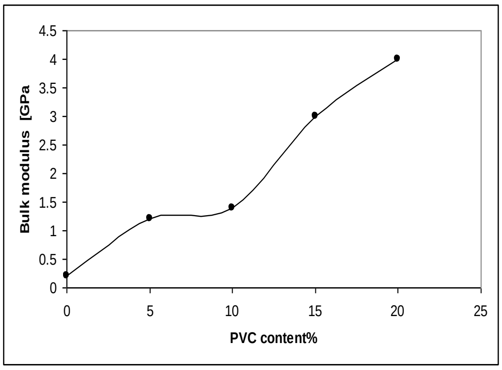

Fig.(3) Variation of Bulk modulus with PVC content in PVC /Epoxy composites

Table (4) Variation Young modulus values E with PVC content in PVC /Epoxy composites

No.	**Weight% of PVC**	**E [GPa]**
1	0	1.8
2	5 %	2.8
3	10 %	3.9
4	15 %	6.2
5	20 %	11.6

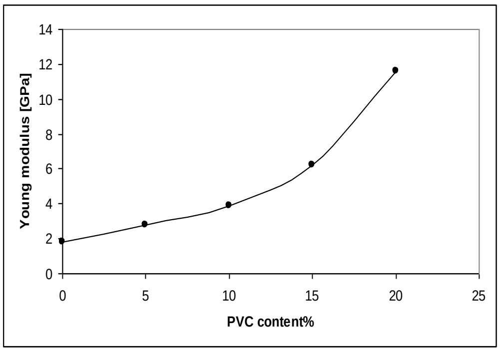

Fig.(4) Variation of Young modulus with PVC content in PVC /Epoxy composites

Table (5) Variation of Poisson's ratio values with PVC content in PVC /Epoxy composites

No.	**Weight% of PVC**	**σ**
1	0	0.47
2	5 %	0.465
3	10 %	0.46
4	15 %	0.458
5	20 %	0.45

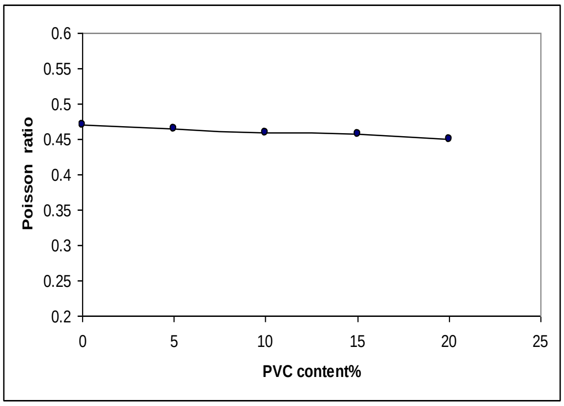

Fig.(5) Variation of Poisson's ratio with PVC content in PVC /Epoxy composites

Table (6) Variation of acoustical impedance I values with PVC content in PVC /Epoxy composites

No.	**Weight% of PVC**	**I [kg/cm^2. sec]**
1	0	4.04
2	5 %	4.8
3	10 %	5.8
4	15 %	7.9
5	20 %	8.9

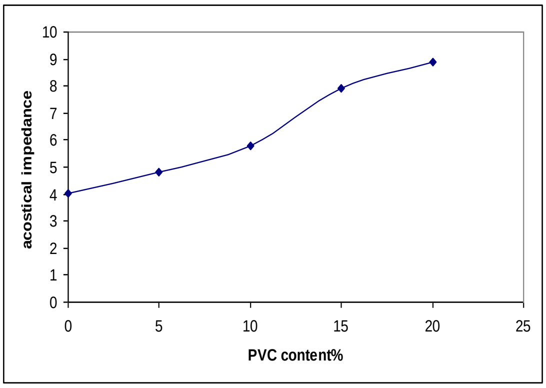

Fig.(6) Variation of acoustical impedance with PVC content in PVC /Epoxy composites

The plotted curves of Figs.(2,3,4) show increasing in the elastic moduli values with the increasing of PVC weight percentage, due to the increasing in density and wave's velocities. The plotted curve of Fig.(4) shows approximately similar values of Poisson's ratio and in the range of solid material (0 – 0.5) [6] .

Fig.(5) shows increasing in acoustical impedance values with PVC content, this indicates that the composite becomes more cross linked and the average speed of compressive pulse was increased[6].

Conclusion

The obtained results showed that increasing PVC content leads to an increase in ultrasonic wave velocity, it was concluded that the changes in the wave velocities can be attributed to the changes in elastic moduli of the polymer matrix that was investigated in this study, due to the increasing in density and the interfacial stresses, which can overlap and change the elastic moduli and also affect the ultrasonic wave velocity, also it was concluded that ultrasound measurements can be employed to describe dynamic mechanical material behavior[5,6].

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