Dynamical Properties of Epoxy–Chopped Rock Wool Composites

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Abstract

Hand- lay up method was used to prepare epoxy (EP) – chopped rock wool composites. The dynamical properties for EP/chopped rock wool composites with different weight percentage of chopped rock wool (2.5, 3.5, 5, 7.5, and 10 wt %) had been studied by using ultrasonic test method (direct method).

Ultrasonic test as a non destructive testing become widely used in industry and reliable measurements, ultrasonic is the study of sound waves of frequencies higher than the upper hearing limit of the human ear (frequency region above 20 kHZ).

A local apparatus according to ASTM C167-82 was prepared to measure the thickness for loose materials to calculate the density of materials like rock wool.

A new sonic viewer device was used to measure the average times of compressional and shear waves(Tp,Ts) respectively which are transit through the composites to calculate their velocities (Vp,Vs) in order to calculate the dynamic elastic moduli such as Poisson ratio (μ), Shear modulus (G), Modulus of elasticity (E), Bulk modulus (B), and other parameters such as acoustic impedance (Z) for all composites.

It was shown that random values of compressional velocity (Vp) were observed for EP/chopped rock wool composites due to random distribution of chopped rock wool which could be as a results of weak interface bond between EP and chopped rock wool. Shear velocity (Vs) values are decreased with increasing weight percentage of chopped rock wool and less than Vp values due to the particles of material are vibrating perpendicular to the direction of shear waves propagation. Slight variation of poisson ratio μ, and bulk modulus B for all composites with increasing weight percentage of chopped rock wool. Larger variation of shear modulus G, and modulus of elasticity E values for EP/chopped rock wool composites due to defects such as voids and weak interface bond, G values decrease with increasing weight percentage of rock wool as a result of decreasing shear velocity values. Almost similar values of acoustic impedance Z are observed and lie between 3.57 to 3.93×10^6 kg/m^{2}sec for all composites.

Keywords: Dynamic elastic moduli, ultrasonic, chopped rock wool.

Introduction

Composite materials are used into various fields, such as aircraft and space structures, because of the excellent characteristics, e.g., light-weight, high ratio of relative intensity and high ratio of relative rigidity [1].

Most sound–absorbing materials are fibrous or porous and are easily pentrated by sound waves. The fibrous materials are composed of either glass fibers or minerals fibers such as rock wool [2]. The major applications of rock wool, glass wool, and slag wool derive from their performance as thermal and acoustic insulators and as filtration media, as materials are noncombustible and resist moisture and short–term wetting, out door insulates, they have extra merit as building and industrial insulation such as furnaces industrial [3].Rock wool an organic and not allow to growth funguses, parasites', and bacteria , help to protection the environment from unclean , in agriculture rock wool can be used as airing earth.

Non destructive evaluation (NDE) is a huge and diverse field. Regarding experimental methodology it includes not only ultrasonic's but also a wide range of complementary techniques such as x–rays, optical technique such as direct visual inspection using microscopic, telescopic, thermal technique such as infrared [4]. Elastic wave energy at ultrasonic frequencies has been successfully heard over the past 35 years. Ultrasonic as a non destructive testing become widely used in industry and reliable measurements, used to study the dynamic properties of materials such as compressional, shear velocitiesVp,Vs, Poisson ratio μ, shear modulus G, modulus of elasticity E, bulk modulus B, and other parameter such as acoustic impedance Z [5].

The investigation of dynamical properties of polymer composites is of great interest at present because of the growing use of these materials for industrial applications likes aircraft structures were the composite shell reduce frequency noise transmission to the aircraft fuselage, rock wool fiber mat used to improves FRP fire resistance [6],[7].

The matrix material was epoxy resin (Sikadur52–A) prepared by the reaction of bisphenol A with the hardener (Sikadur 52 – B) epichlorohydrine as shown in Fig.(1) [8] , supplied by company sanyicad, kaynatce - Turkey as matrix,(Density1.1*10^3 kg/ m^3) ,loose rock wool supplied by Jordan rock wool company was added to the matrix, the rock wool insulation products have a mean diameter about 4 to 6 μm and the density range of rock wool 23 – 200 kg /m^3[3].

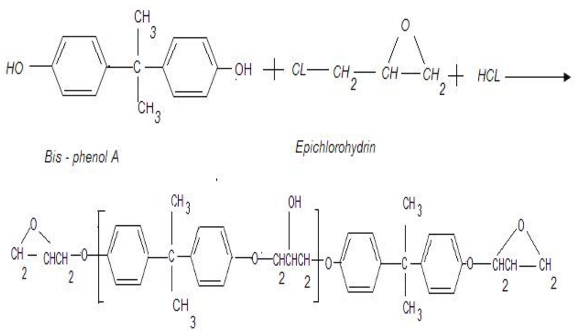


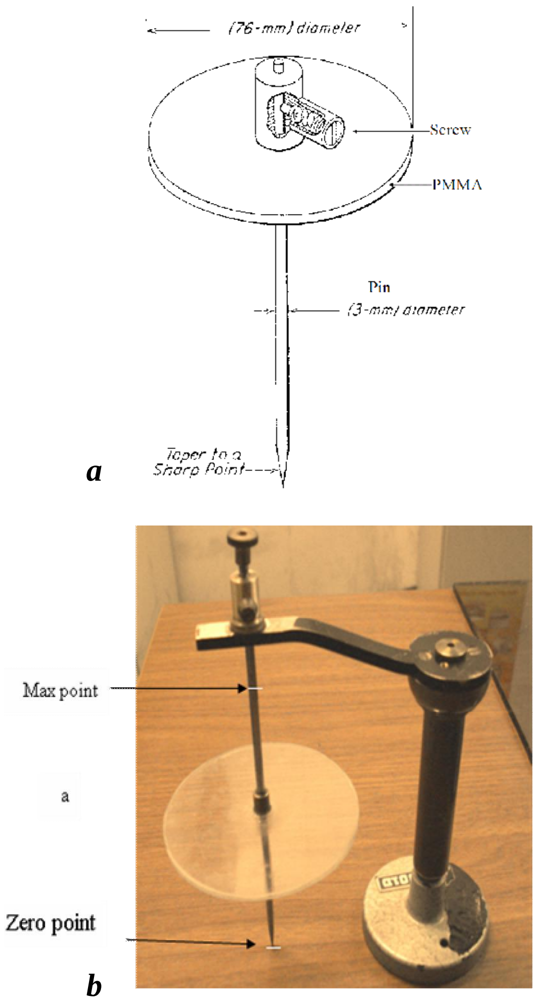
Fig.(1) Epoxy (bisphenol A with epichlorohydrine) [8].

Experimental part and measurements Employed Materials

Materials preparation

Hand- lay up method was used to prepare epoxy resin; a clean disposable container was used for mixing an exact amount of hardener with the EP with ratio 2: 1 part by weight. An aluminum mould with dimensions 4.5 cm, 4.5 cm, 10.5cm consists of eight plate's joints was use to prepare samples. Aluminum plate mould was cleaned with water and soap solution followed by distilled water and put it in oven at 50 °C for one hour, then coated with wax and nylon to prevent adhesion of samples with aluminum mould before curing and left it to dry at room temperature.

An electronic balance of accuracy 0.01 was used to measure the weight of chopped rock wool (different weight percentage) with epoxy resin. A local apparatus according to ASTM C167-82 was prepared to measure the thickness for loose materials(rock wool) to calculate the density of rock wool as shown in Fig.(2)[9].



Figs. (2) a-Depth gage for thickness of loose material and density measurements (ASTM – standard C167-82) [9], b- Local apparatus for thickness measurement of loose materials.

The composites were prepared by mixing epoxy resin (EP) and chopped rock wool with different weight percentage (2.5, 3.5, 5, 7.5, and 10 wt %) by using hand- lay up method. Part of EP resin was poured into mould. The different weight percentage of rock wool was added then the remained matrix was added. Aluminum plate was used to compress the composite in order to have a uniform thickness and getting rid of bubbles. EP/chopped rock wool composites were cured at room temperature for 24 hours then removed from the mould and release it after four hours and. To obtain smoothing surfaces of composites using smoothing paper. The prepared EP resin and composites are labeled as shown in Table (1), Fig.(3) shows the prepared reference sample (1), and composites.

Table (1)
Reference sample EP (1) and EP/random chopped rock wool composites with different rock wool weight percentage.

Samples	*Composites*
1	Reference sample
F	EP/2.5 wt % random chopped rock wool
G	EP/3.5 wt % random chopped rock wool
H	EP/5 wt % random chopped rock wool
I	EP/7.5 wt % random chopped rock wool
J	EP/10 wt % random chopped rock wool

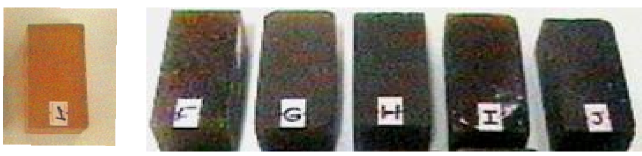


Fig.(3) Reference sample EP (1) and EP/ rock wool composites.

Ultrasonic test

In this study we are focusing on the ultrasonic waves such as the compressional and shear waves (with frequencies 33, and 55 kHZ respectively) as they are the basic waves propagation in materials. A new sonic viewer device model–5217A was used to measure the transmission time in microsecond then recorded the times after folding the sample 4 times to calculate average times of compressional, shear waves of EP and EP/ chopped rock wool composites. Coupland joint (greese) was used to joint transducers and sample The average times of compressional, and shear waves of reference sample (1), and EP/chopped rock wool composites are shown in Table (2).

Table (2)
Average times of compressional wave (Tp) and shear wave (Ts) of reference sample EP (1), and Ep/random chopped rock wool composites.

Samples	*Average times of compressional wave (Tp) (μ sec)*	*Average times of shear wave (Ts) (μ sec)*
1	29.4	94
F	30.6	92
G	31.6	101.6
H	29.6	117.6
I	31.2	108
J	30	102.4

The difference of average time's values of waves is due to randomly distribution of voids inside rock wool.

The average times (Tp,Ts), and length path d (9.7cm) are used to calculate compressional, and shear velocities (Vp,Vs) in m/sec as shown in equations below[10].

$$Vp=\frac{d}{T_P} \quad \ldots\ldots (1)$$

$$Vs=\frac{d}{T_S} \quad \ldots\ldots (2)$$

Where d: Sample thickness (9.7cm).

Determination of the dynamic elastic moduli

For most materials that are stressed in tension and at relatively low levels, stress and strain are proportional to other through the equation

$$s = Ee \quad \ldots\ldots (3)$$

This is known as Hooke's law,where σ: Applied stress on the material (GPa), E: Eliastic conestant(modulus of elasticity or young's modulus in GPa), e : the strain of material [11]. If body is perfectly elastic, it behaves according to Hooke's law, and strain is proportional to stress. Most of the elastic constants are measured or defined in terms of ratio of stress to strain produced. The different constants are defined in terms of different kinds of force or stress (tension, compression, shear, etc) [12].The dynamic elastic moduli was calculated from the above Vp and Vs which are poisson ratio(μ), shear modulus(G), modulus of elasticity(E),bulk modulus(B), and other parameters such as acoustic impedance(Z) are shown in equations below.

$$\mu=\frac{\frac{1}{2}\left(\frac{V_P}{V_S}\right)^2-1}{\left(\frac{V_P}{V_S}\right)^2-1} \quad \text{.......} \quad (4)$$

$$G = r\ Vs^2 \quad \text{.......} \quad (5)$$

Where:- G: shear modulus (GPa), r : density of material (Kg/m^3),Vs : shear velocity (m /sec).

$$E=2G(1+\mu) \quad \text{.......} \quad (6)$$

$B = -V\frac{dp}{dv}$, where V is the volume and p the pressure.

$$B = r\ (Vp^2 - \frac{4}{3}Vs^2) \quad \text{.......} \quad (7)$$

Were: B: bulk modulus (GPa)

$$Z= r\ Vp \quad \text{.......} \quad (9)$$

Where: Z: acoustic impedance (Rays = kg/m^2.sec [5, 13, 14].

Results and Discussion

Density of rock wool was calculated by using a local apparatus and it was equal to 42.53Kg/m^3. Density of reference sample 1 and the average densities of EP/ chopped rock wool composites were calculated by using Archimedes principles and they were equal to 1134, 1152 Kg/m^3 respectively.

Compressional velocity (Vp) of reference (1) and EP/chopped rock wool composites are shown in Fig.(4). The results show the values of reference (1) is equal to 3316 m/sec, random values of compressional velocity for EP/chopped rock wool composites due to random distribution of rock wool in the matrix, the variation between the maximum and minimam values of compressional velocity is equal to 6 % which could be as a results of un uniform distribution voids inside rock wool structure.

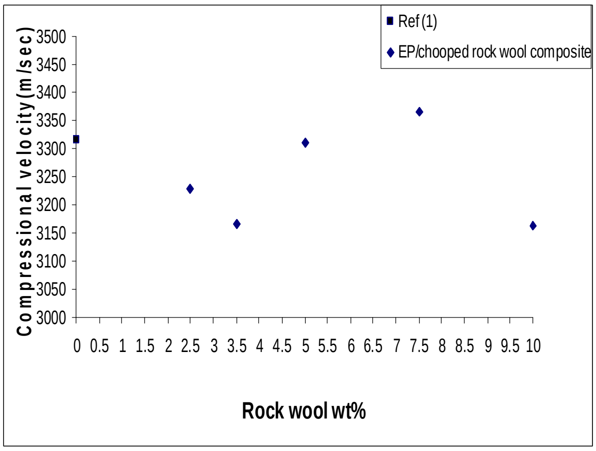


Fig.(4) Compressional velocity (Vp) versus rock wool wt% of EP/chopped rock wool composites.

Shear velocity (Vs) of reference (1) and EP/chopped rock wool composites are shown in Fig.(5), where the results show that the average values of shear velocity for reference sample (1) is equal to 1037m/sec, the values of shear velocity for EP/chopped rock wool composites are decrease with increasing weight percentage of rock wool as a results of rock wool content inside the matrix. The variation between the maximum and minimam values of shear velocity is equal to 22.4 %.Zimmer reported that the undirectional of fibers array causes heterogeneous structure of the material results in dispersion of waves propagation [15].

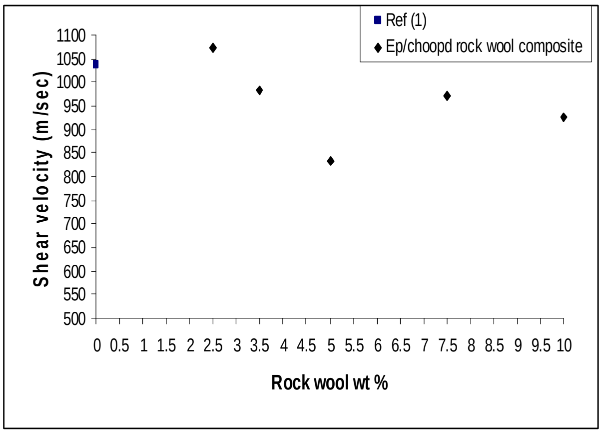


Fig.(5) Shear velocity (Vs) versus rock wool wt% of chopped rock wool composites.

Randomly behavior of wave velocities propagate in the composite material are observed and the values of compressional velocity are greater than the values of shear velocity due to the particles of material are vibrating along the direction of compressional waves propagation while the particles of material are vibrating perpendicular to the direction of shear waves propagation. [16].

Dynamical elastic moduli are calculated and the results of poisson ratio (μ), shear modulus (G), modulus of elasticity (E), bulk modulus (B),and other parameters such as acoustic impedance (Z) are shown below.

Poisson ratio of reference (1) and EP/chopped rock wool composites are shown in Fig.(6), where the results show that the values of poisson ratio for reference (1) is equal to 0.45, slight vary of poisson ratio for EP/chopped rock wool composites with increasing weight percentage of rock wool. The variation between the maximum and minimum values of poisson ratio is equal to 6.2 % due to randomly distribution of voids inside rock wool. These results agree with the values of poisson ratio for solid materials (0 - 0.5) [17].

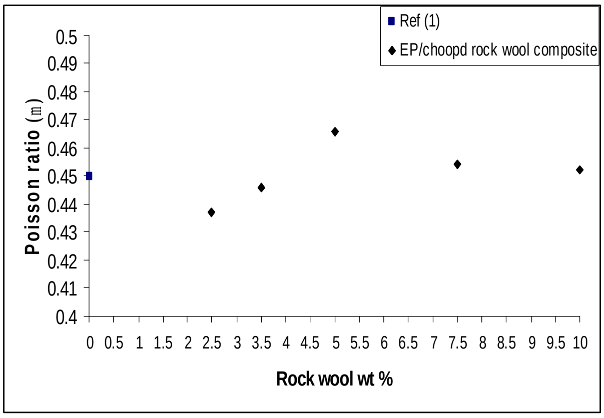


Fig.(6) Poisson ratio (μ)) versus rock wool wt% of EP/chopped rock wool composites.

Shear modulus (G) of reference (1) and EP/chopped rock wool composites are shown in Fig.(7), where the results show that the values of shear modulus for reference (1) is equal to 1.3 GPa, while the values of shear modulus for EP/chopped rock wool composites almost decrease with increasing weight percentage rock wool as a result of decreasing the shear velocity values due to defects such as voids as shown in Figs. (8). The variation between the maximum and minimum values of shear modulus is equal to 32.2%.

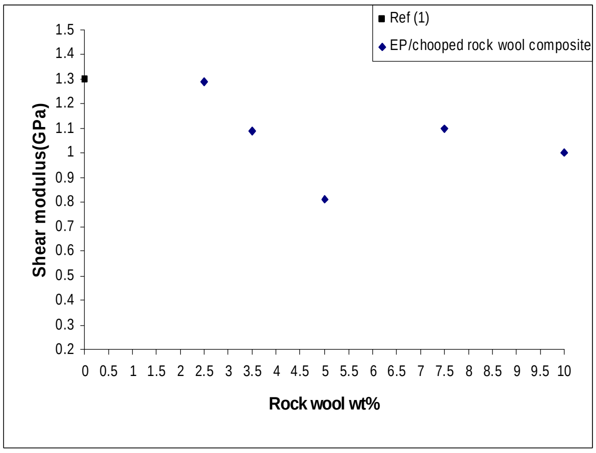


Fig.(7) Shear modulus (G) versus rock wool wt% of EP/chopped rock wool composites.

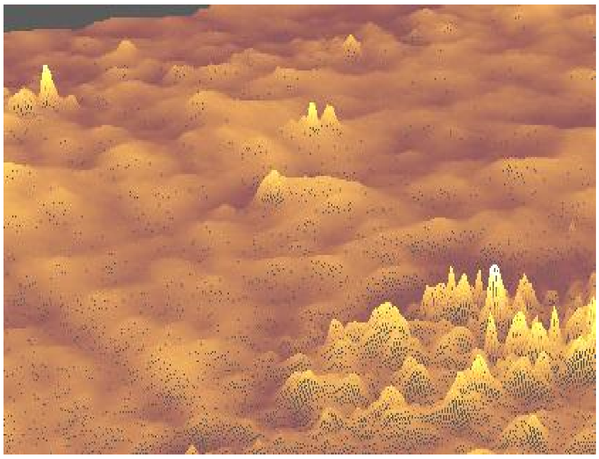


Fig.(8) Defects (voids) inside EP/chopped rock wool composites (sample H).

Modulus of elasticity (E) of reference (1) and EP/chopped rock wool composites are shown in Fig.(9). Where the results show that the modulus of elasticity for reference (1) is equal to 3.77 GPa, while the values of modulus of elasticity for EP/chopped rock wool composites decrease with increasing weight percentage of rock wool due to weak interface bond between EP and chopped rock wool due to defects such as voids inside rock wool as shown in Fig.(10). The variation between the maximum and minimum values of modulus of elasticity is equal to 35 %.

In Fig.(10). The variation between the maximum and minimum values of modulus of elasticity is equal to 35 %. maximum and minimum values of modulus of elasticity is equal to 35 %.

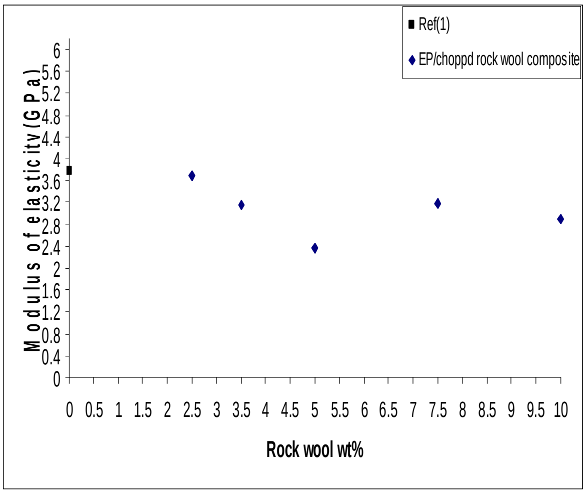


Fig.(9) Modulus of elasticity (E) verse rock wool wt% of EP/chopped rock wool composites.

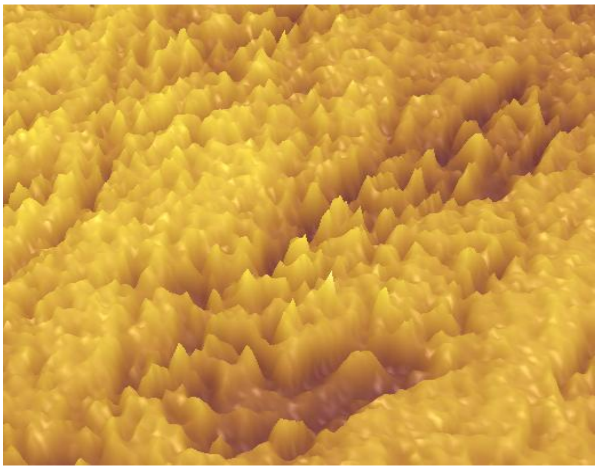


Fig. (10) Weak interface bond between EP and chopped rock wool due to voids (rock wool content).

Bulk modulus (B) of reference (1) and EP/chopped rock wool composites are shown in Fig.(11). Where the results show that the values of bulk modulus for reference (1) is equal to 10.8 Gpa, the values of bulk modulus for EP/chopped rock wool composites are almost similar and slight variation with increasing weight percentage of rock wool. The variation between the maximum and minimum values of bulk modulus is equal to 16.9 %.

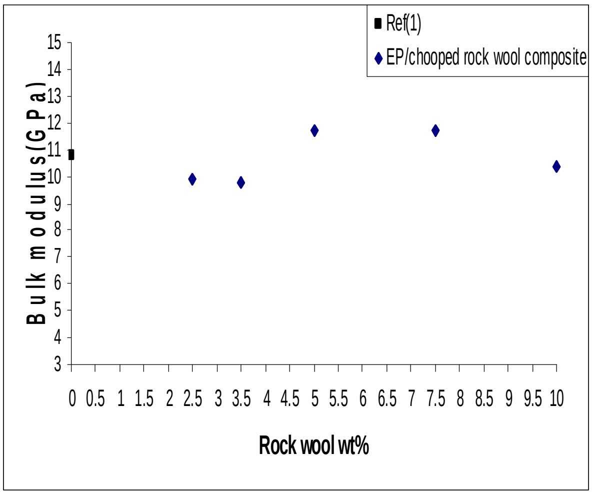


Fig.(11) Bulk modulus (B) versus rock wool wt% of EP/ chopped rock wool composites.

Acoustic impedance (Z) of reference (1) and EP/chopped rock wool composites are shown in Figure (12).where the results show that the values of acoustic impedance for reference (1) is equal to 3.76 $kg/m^2.sec$, while the values of acoustic impedance for EP/chopped rock wool composites almost similar with increasing weight percentage of rock wool and lie between 3.57 to 3.93×10^6 kg/m^2sec for all composites. The variation between the maximum and minimum values of acoustic impedance is equal to 9.1 %. The values of acoustic impedance agree with the published data for unsaturated polyester /carbon fiber composites acoustic impedance with range 2.5–4.5$\times$ 10^6 kg/m^2 sec, unsaturated polyester /glass fiber composites acoustic impedance 3.5 $\times$ 10^6 kg/m^2 sec [18]. Yet the acoustic impedance for light weight aggregate concrete used for building is equal to 0.82×10^6 kg/m^2sec [19], and for light weight concrete / polystyrene grains is equal to 2.3 $\times$ $10^6 kg/m^2sec$ [20] which is less than our acoustic values for EP/chopped rock wool composites.

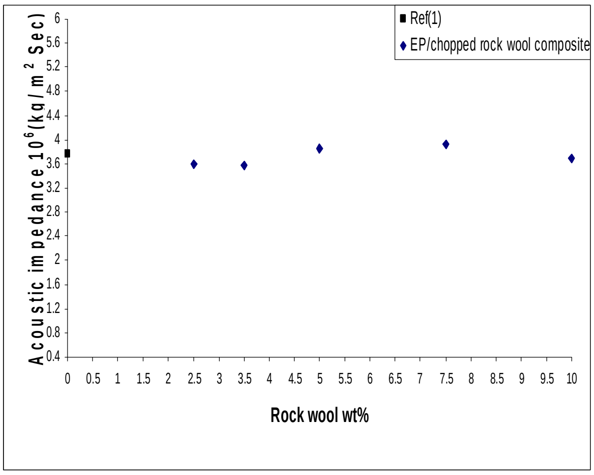


Fig.(12) Acoustic impedance (Z) versus rock wool wt% of EP/chopped rock wool composites.

Conclusions

Random values of Vp for all composites due to random distribution of rock wool which could be as a results of voids inside rock wool structure. Vs values are decrease with increasing weight percentage of chopped rock wool and less than Vp values due to the particles of material are vibrating perpendicular to the direction of shear waves propagation. Slight variation of μ, and B for all composites with increasing weight percentage of chopped rock wool. Larger variation of G, and E values for EP/chopped rock wool composites. Almost similar values of Z lie between 3.57 to $3.93*10^6$ $kg/m^2 sec$ for all composites.

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الخلاصة

استخدمت الطريقة اليدوية لتحضير متراكبات الايبوكسي- الصوف الصخري المقطع . درست الخصائص الديناميكية لمتراكبات الايبوكسي- الصوف الصخري المقطع وبنسب وزنية مختلفة (2.5, 3.5, 5, 7.5, and 10 wt %) باستخدام طريقة ان الفحص بالموجات فوق الصوتية (الطريقة المباشرة). الفحص بالموجات الفوق الصوتية هو فحص لأاتلافى واسع الأستخدام فى الصناعةومن القياسات الموثوق بها وتستخدم لدراسة موجات الصوت والتى تكون تردداتها أعلى من مدى الترددات المسموعة من قبل الأذن البشرية ($20\ KH_Z$). تم تحضير الجهاز المحلى وحسب المواصفة الأميريكية الخاصة بفحص المواد ASTM C167-82 لقياس سمك المواد السائبة لحساب كثافتها.

أستخدم الجهاز (new sonic view*er*) لقياس معدل أزمان الموجات الانضغاطية والموجات القصية (Tp,Ts) على التوالى والمارة خلال هذة المتراكبات لحساب السرع (Vp ,Vs) لهذة الموجات وذلك لغرض حساب معاملات المرونة الديناميكية مثل نسبة بوازون (μ) ,معامل القص (G) ,معامل المرونة (E) ,المعامل المرونة الحجمي (B) والممانعة الصوتية (Z). أظهرت النتائج أن قيم السرعة الأنضغاطية Vp تكون عشوائية لمتراكبات الايبوكسي- الصوف الصخري المقطع والذى يعود الى عشوائية توزيع الصوف الصخري ونتيجة لضعف الترابط بين الايبوكسى والصوف الصخرى المقطع وقيم السرعة القصية Vs تنخفض مع أزدياد النسبة الوزنية للصوف الصخرى المقطع وتكون أقل من قيم السرعة الأنضغاطية يعود السبب الى تعامد أهتزاز جسيمات المادة مع أتجاة أنتشار الموجات القصية.أن تغير قيم نسبة بوازون μ ,المعامل الحجمي B يكون طفيفا مع أزدياد النسبة الوزنية للصوف الصخرى المقطع ولكل المتراكبات. أما قيم معامل القص G ومعامل المرونة E يكون كغير ها كبيرا لمتراكبات الايبوكسي- الصوف الصخري المقطع بسبب وجود العيوب فى هذة المتراكبات كالفجوات وضعف الترابط بين الايبوكسى والصوف الصخرى المقطع , ان انخفاض قيم معامل القص G مع ازدياد النسب الوزنية للصوف الصخرى المقطع هو نتيجة لأنخفاض قيم السرعة القصية. أما قيم الممانعة الصوتية Z غالبا ما تكون متشابهة وهى ما بين 3.57 to $3.93\times10^6\ kg/m^2sec$ لكل المتراكبات.