Acoustic and Mechanical Properties of Polymer Composites Reinforced by Pre-Deformed Palm Fiber

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ABSTRACT

This research was carried out to study the mechanical properties and thermal and acoustic insulation properties of prepared polymer composite. Petiole date palm fibers with the length (2-3mm) and with different volume fraction ratio (10, 20, 30 and 40%) were used as filler in preparation of polymer composite.

The research imply study effect of pre- deformation for petiole date palm fiber by chosen compression loads (0, 2, 4 and 6 MPa) on the mechanical properties as well as on the thermal and acoustic insulation properties of prepared composites. It was concluded that the pre-deformation to the fibers improves the thermal and acoustic insulation properties of prepared composite, as well as an increase in the tensile strength and hardness values with increasing compression load on the fibers. The highest values of the tensile strength and hardness reach to (133MPa) and (106) respectively for the polymer composite filled with 40% volume fraction of petiole date palm fibers which pre-deformed under compression load equal to 6 MPa.

Keywords: palm fibers, compression load, thermal & acoustic insulation.

الخواص الصوتية والميكانيكية لمتراكبات بوليمرية مقواة بألياف النخيل المشوه مسبقا

الخلاصة

البحث الحالي يدرس الخواص الميكانيكية والعزل الحراري والصوتي لمادة متراكبة بوليمرية محضره. استخدمت الياف ساق شجرة النخيل بطول (mm 3-2) وبكسور حجميه مختلفه (40% and 30, 20, 10) كحشوات في تحضير المتراكبات البوليمرية.

وتناول البحث دراسة تأثير التشوية المسبق لاليـاف ساق النخيل تحت ضغوط مختارة (6 MPa and 4, 2, 0) على الخواص الميكانيكية علاوة على خواص العزل الحراري والصوتي للمتراكبات المحضره. وقد استنتج ان التشويه المسبق للالياف يحسن خواص العزل الحراري والصوتي. فضلاً عن حصول زيادة ملحوظة في قيم الصلادة ومقاومة الشد مع زيادة الحمل الأنضغاطي المسلط مسبقا على الالياف. وبلغت اعلى قيم لمقاومة الشد وصلادة (133MPa) و(106) على الترتيب للعينات المحضرة من الياف ساق شجرة النخيل بنسبة كسر حجمي مقداره (40%) والمشوه مسبقا تحت حمل انضغاطي مقداره (6 MPa).

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INTRODUCTION

The use of natural fibers for the reinforcement of the composites has received increasing attention both by the academic sector and the industry, because of their advantages over other established material. They are easy availability, competitive specific mechanical properties, environmentally friendliness, high toughness, non-corrosive nature, low density, good thermal properties, renewability and biodegradability [1-3].

Natural fiber composites have been studied and reviewed by a number of researchers (Debasish D., et al.(2004)[4], H.P.S. Abdull Khalil, et al.(2006)[5], Saira Taj, et al. (2007)[6], A. S. Singha and V. K. Thakur (2008)[7], A. S. Singha and V. K. Thakur (2oo9)[8], M. J. Mohd Nor et al. (2010)[9] K. Ramanaiah et al. (2012)[10]). The mechanical properties and physical properties of natural fibers vary considerably depending on the chemical and structural composition, source, age, fiber type, growth condition and separating techniques of the fiber [5,11]. The chemical compositions of natural fibers depend on various factors. It varies with the geographic location, climate, type of fiber, plant part, and soil conditions, etc. [12], most plant fibers, and except for cotton are composed of cellulose, hemicelluloses lignin, waxes and some water-soluble Compounds [6]. Natural fiber reinforced polymer composites have recently gained importance in various application as building materials, automotive, aerospace, infrastructure, marine etc. One of the major problems associated with the use of natural fibers in composites is their high moisture sensitivity leading to severe reduction of mechanical properties and delaminating. The reduction in mechanical properties may be due to poor interfacial bonding between resin matrix and fibers. The properties can be improved both by physical treatment and chemical treatment [7, 13-16].

Moreover many studies focused in developing natural fibers as alternative sound absorber and thermal insulation from recycled material, thus alternative raw materials those are of low cost, renewable, plentiful and save for environment and human health is needed . Paddy straw was reported suitable for acoustic panel because of its high elasticity and hollow space [17], coconut coir fiber has good sound absorption at higher frequencies but less for the lower frequencies, so did the oil palm fiber. Higher noise absorption of oil palm is due to its higher density [18-19]. Then, industrial tea-leaf-fiber waste material also has sound absorption properties at high frequencies [20]. Besides, Kenaf can be property seen as an alternative, especially for thermo-acoustic application and sound barriers [21]. The date palm tree an important member of the palm tree. This tree is a common source of natural fibers, which are used in many different applications. This research was carried out to study the potential use of date palm fibers in replacing synthetic based fibers for thermal insulation and sound absorption application. So, the objective of this study was to investigate the effect of pre deformation of date palm fibers on mechanical and thermal and acoustic insulation properties of polymer composites.

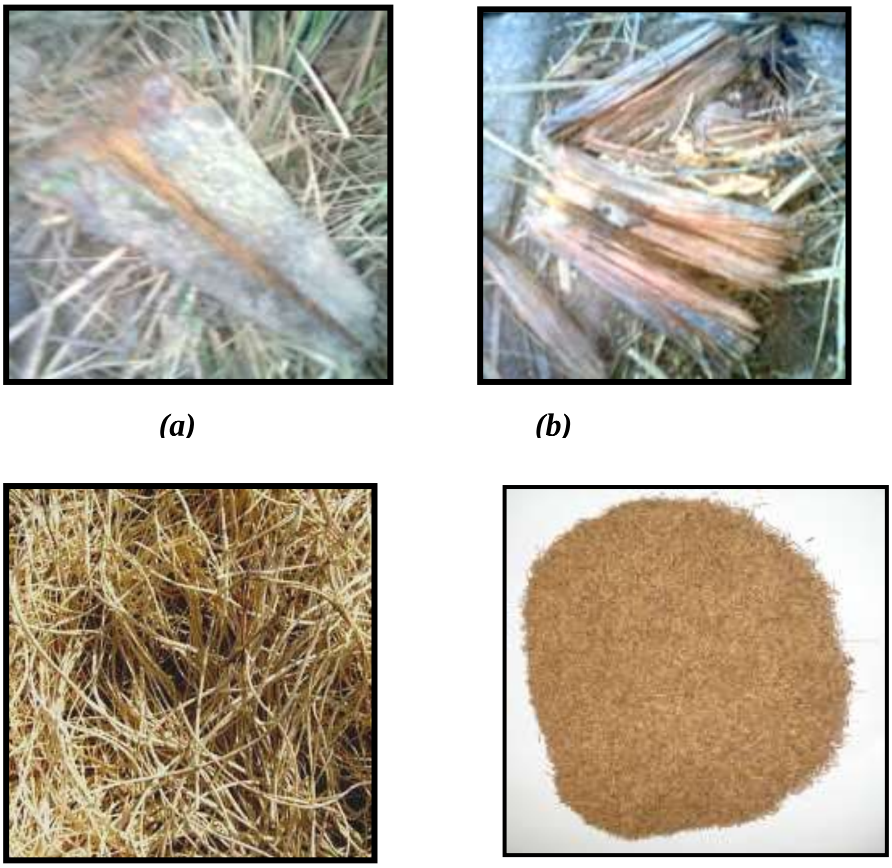
EXPERIMENTAL

Material

Unsaturated polyester resin (UP) was used as matrix material, supplied by (SIR) Saudi company. Was a viscous liquid, transparent at room temperature and thermally hardened, was mixed with hardener (supplied by the company itself, which is a Methyl Ethyl Keton peroxide) to form a strong permanent band converted to a solid state. The weight ratio between hardener and resin was 2 gm of hardener per 100 gm of the resin.

Palm fibers were collected locally from the date trees obtained mainly from Baghdad farms in middle of Iraq. The fibers were taken from petiole of date palm (bases leaflet date palm tree) as shown in Figures (1, a, b).

As a first step the fibers were washed thoroughly with detergent powder in order to remove dust and mud. After those fibers were soaked in hot distilled water for 2h, dried for 72 h in air at room temperature, date palm fibers with different lengths obtained. The fibers were threaded in to pieces and stretched to a specified length and width, these fibers were chopped into (2-3) mm length as shown in Figure (1, c, d).



(a) ***(b)*** ***(c)*** ***(d)***

Figure (1): (a), (b) data palm Petiole, (c) petiole fibers, (d) Short petiole fibers.

Chemical treatments

Chemical treatments were employed for surface modification of date palm fibers. Fibers were soaked in 5% sodium hydroxide (NaOH) for 48 hours and then washed many time in distilled water and dried in a hot air oven at 70°C for 8h and then stored in a vacuum desiccators. The chemical composition analysis and moisture content for these fibers is shown in Table (1).

Table (1) Chemical composition and moisture Content of date palm fibers.

Material	Cellulose	Lignin	Pectin	Moisture content
Weight percentage	75.6	16.8	4	3.6

Composite preparation

Hand lay-out technique was used to prepare the composite specimens, a mould of size (250×250×5) mm^3 was made from glass. Sheet of polyvinyl alcohol substance was fixed on the inner mould faces before casting to facilitate the releasing of casting polymer and having smooth faces. Palm fibers with dimension (2-3 mm) after proper purification surface modification and drying, divides into four parts which were subjected to various compression loads (0, 2, 4 and 60 MPa) respectively. Then each part were thoroughly mixed with polyester resin by different fibers loading (10, 20, 30 and 40%) in terms of volume fraction, then the mixture was poured into the mould and allowed to cure for 48h at room temperature (27°C). After solidification, all the specimens (sheets) released from the mould then post cured in an electrical oven at 55°C for 2h. Composite sheets of size (240×240×5) mm^3 were prepared for acoustic insulation test, and anther composite sheets cut off and machined according to standard specifications to produce samples conforming for mechanical (tensile and hardness) and thermal conductivity test.

Mechanical test

Samples were prepared for the tensile test in accordance with ASTM D638-87 procedure, computerized universal tasting machine model (CUTM-1866) ETS Interlaken technologic company. The test was conducted at the constant cross head speed of the order of 10mm/min. tensile load was applied till the failure of the sample and stress- strain curve was obtained. Each sample was tested for three times and average results have been reported.

The hardness test carried out on a Durometer on Shore-D scale (DIN-53505) standard is used for hard polymer materials with specimen dimensions of (40mm diameter and 5mm thick).

Thermal conductivity test

For the measurement of thermal conductivity the apparatus used of the standard Lee's disk method. This consists of three copper plates (A, B and C) and a 6W electrical plate heater of the same diameter as the copper plates (Griffin and George ltd.). The sample to be studied was cut to the same diameter as the copper plates (40) mm and to a thickness of approximately (5) mm. The thermal conductivity value of the specimen (K) was calculated from the following [22]:

$$K= [ed/2\pi r^2(T_B-T_A)]\times [a_s(T_A+T_B)/2+2a_AT_A] \quad .....(1)$$

Where e is given by:

$$e=VI/[a_AT_A+a_s(T_A+T_B)/2+a_H(T_B+T_C)/2+a_B T_B + a_C T_C] \quad ....(2)$$

d (thickness of the specimen) = 5mm

r (radius of the specimen) = 20mm

and a_A, a_B, a_C, a_S and a_H are the exposed surface areas of A.B,C and the specimen and heater respectively. Areas a_A and a_C include the flat ends of the discs. T_A,T_B and T_C are the heater and (I) is the current which flows through it. K = thermal conductivity in (w / m.˚C).

Sound absorption coefficient test

The sound absorption coefficient (SAC) measurement was carried out according to ASTM E-336. SAC of the test specimen was determined by comparing the noise levels sampled inside the source and receiving rooms between which the test specimen (dimensions (240×240×5) mm^3) separating them. Sound measurement was carried out inside the two rooms. The loudspeaker is fed with white noise in 1/3 octave band. The averaged sound pressure level was measured in1/3 octave band frequencies, from 100Hz to 5000Hz. If the sound absorption of the source room is A_1 and the sound absorption of receiving room is A_2, the sound absorption coefficient of the test sample is given by [23]:

$$\alpha = (A_1-A_2) / S \qquad \text{--- (3)}$$

Sound absorption of the room (A_1 and A_2) is calculated by:

$$A = 0.92VD / C \qquad \text{--- (4)}$$

V = Volume of room,m^3 C = Speed of sound, m/sec D = Rate of decay, dB/ sec

S = Surface area of the sample, m^3 **.**

RESULTS AND DISCUSSION

Mechanical properties

Mechanical properties of fiber reinforced composites depend on the nature of the fiber, matrix materials, the nature of the fiber matrix interface and of the inter phase region. Even a small change in the physical nature of the fiber for a given matrix may result in prominent changes in the overall mechanical properties of composites. So this research was carried out to study the effect of pre-deformation of date palm petiole fibers (which subjected to various compressive loads (0, 2, 4, and 6MPa)) on the mechanical properties for the polyester resin reinforced by these fibers. Figures (2) and (3) illustrate the influence of preformed load on tensile strength and young modulus of Petiole fiber-polyester composite respectively. From these figures it was shown that the tensile strength and young modulus values increase when polyester resin reinforce by petiole date palm fibers, and the rate of increment in these values increased when petiole date palm fibers pre-deformed before mixed with resin, and it can also be seen that as the compression load of the fibers increases the tensile strength and young modulus values are increased, whereas the elongation values decreased as compression load increased as shown in Figure (4) and the rate of decreasing is more with rise fiber content. Figure (5) shows the shore hardness of composite increases with increasing fibers content as well as compressive load, in general, this increase of shore hardness of composites are due to natural date palm fibers because high compaction and homogeneity distribution of these short fiber [7].

As shown from these results there was significant improvement in mechanical properties as a resultant of pre-deformed palm fibers by subjected to a compression load, this might be leads to increased density and changes in the surface structure of the fibers, and that leads to larger surface area and more fiber-matrix interaction, and this improve the compatibility and wettability between the fibers and polymer [12], and also petiole palm fibers consist of cellulose and lignin as shown in Table (1). Cellulose is principally for the strength of natural fibers because of its specific properties such as high degree of polymerization and linear orientation, as well as the formation of a chemical adhesion between polyester resin and cellulose of petiole palm fibers [11], all these parameter increase the efficiency of the stress transfer from matrix to the fiber and hence increase in mechanical properties.

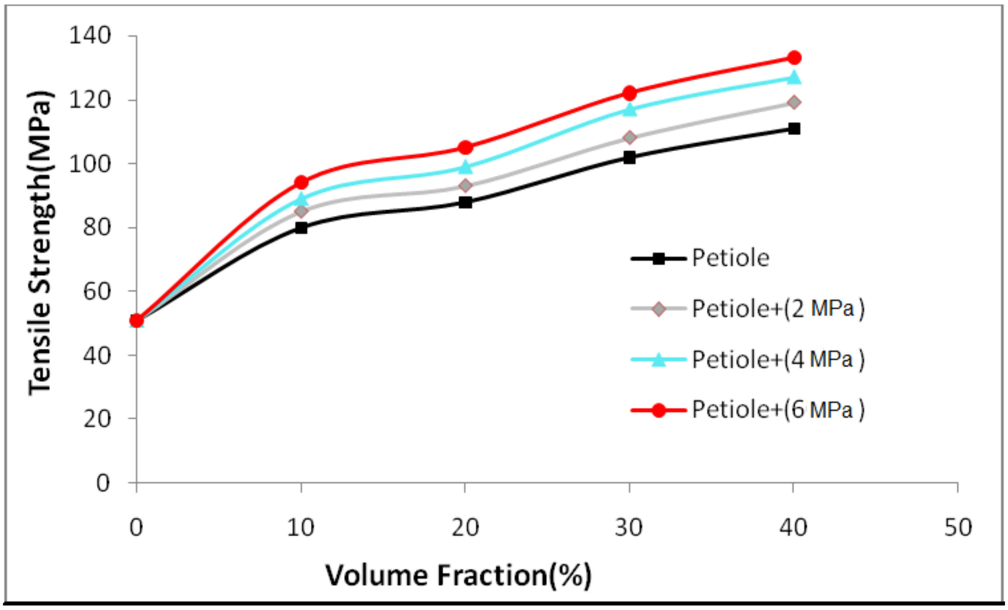


Figure (2): Tensile strength of polyester- composite as a function of Petiole date palm

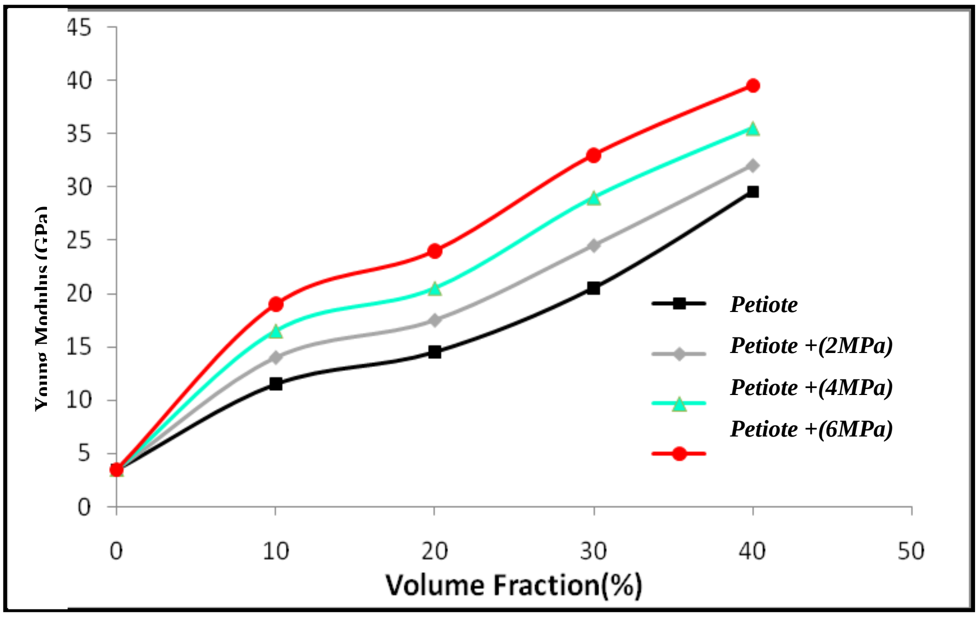


Figure (3): Young Modulus of polyester- composite as a function of Petiole date palm fiber content which subjected to various compression loads

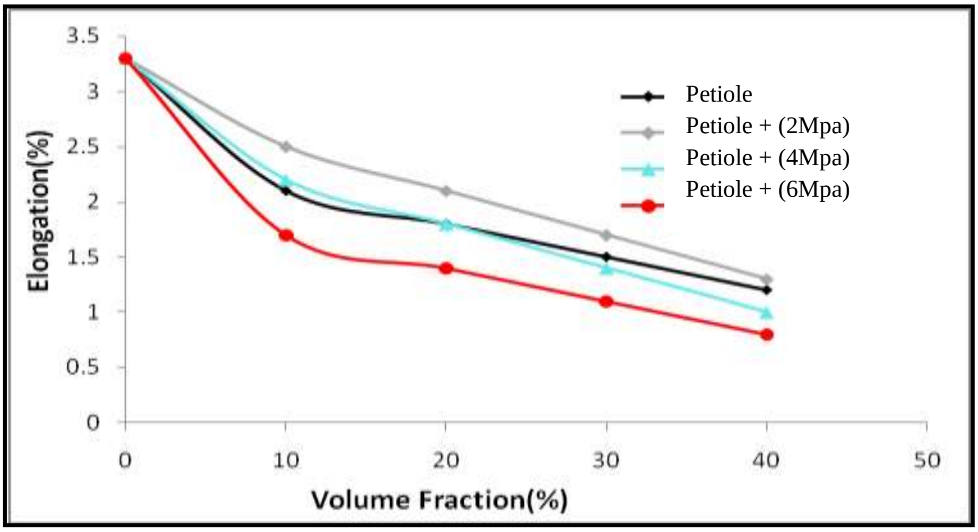


Figure (4): Elongation of polyester- composite as a function of Petiole date palm fiber content which subjected to various compression loads.

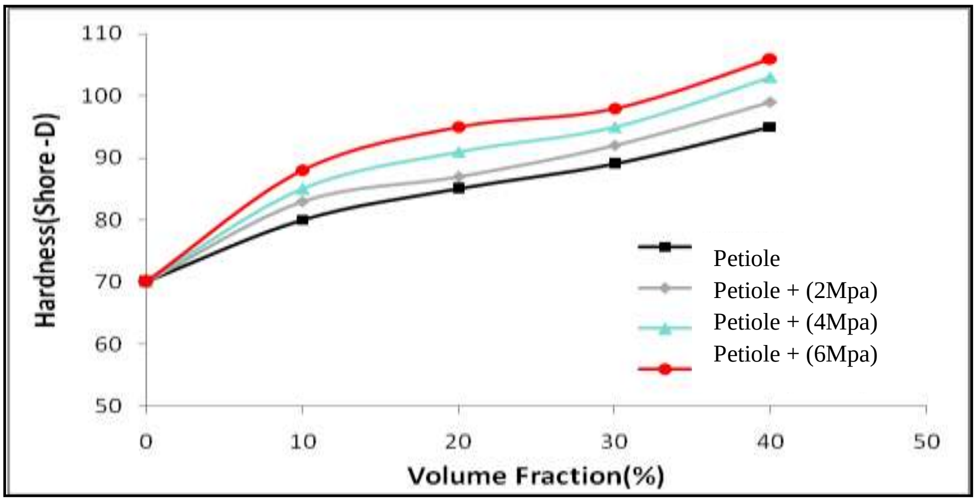


Figure (5) Hardness of polyester- composite as a function of Petiole date palm fiber content which subjected to various compression loads.

Thermal conductivity

The thermal conductivity of many engineering materials depends upon the volume fraction of different phases and their connectivity. So one objective of this study was to investigate the effect the per-deformed petiole date palm fibers by compressive load on thermal insulation properties Figure (6) shows that thermal conductivity values decrease when polyester resin fill by petiole date palm fibers, and the rate of decrement in these values increased when petiole date palm fibers pre-deformed before mixed with resin, so the pre-deformed petiole date palm fibers lower thermal conductivity values for all prepared composites, and these values more decrease as the compressive load increased.

From the foregoing results it is clear that the thermal conductivity of the matrix decreases to a greater extent when reinforced with date palm fibers. The major reason for this is the thermal conductivity value for the palm fiber is lower than the polyester matrix, because these fibers content high weight ratio of cellulose as shown in Table (1), which have good thermal insulation properties, therefore as the load fiber increases the thermal conductivity of the prepared composite decreased, as well as the nature of palm fibers as a hollow tubular structure [24], which leading to the transfer heat energy through it in two method (conduction and convection) then the elastic waves (phonon) transfer through the matrix material and solid part of the palm fiber by vibration motion of the atoms and due to the covalent band and upon the arrived of phonon to the hollow part of palm fiber phonon will suffer obstruction in there motion because the medium presence is different from the first medium, which will lead to decrease thermal conductivity values of the prepared composites.

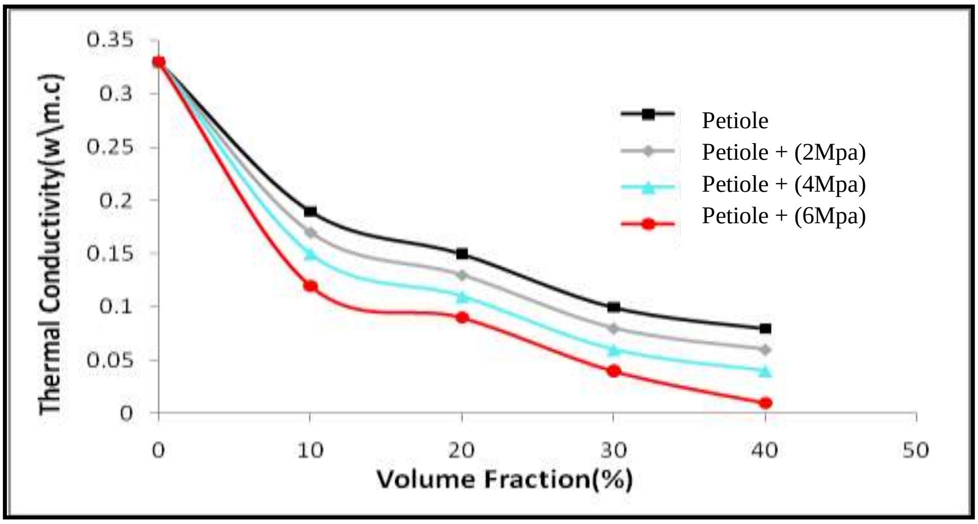


Figure (6): Thermal conductivity of polyester composite as a function of Petiole date palm fiber content which subjected to various compression loads.

Acoustic absorption coefficient

The main parameters critical in the determination of the acoustic properties are the acoustic absorption coefficient. Figures (7, 8, 9 and 10) shows the experimental results obtained for pure polyester material and polyester-date palm fiber composite, the composites samples shows higher a absorption coefficient compared to the pure polyester material, this related to the natural of the palm fibers which have higher acoustic insulation compared to polyester material because the date palm fibers content high weight ratio of cellulose which have good acoustic insulation, furthermore petiole date palm fibers as a hollow tubular (cellular fibers) structure is expected to yield good reinforcement with high damping properties, and have the capacity of reduce the transmission of vibration by mechanical distribution to a structure. Also these figures show that the Pre-deformed date palm fiber enhanced the acoustical behavior of preparation composite samples, increasing compression load enhances the acoustic absorption of all preparation composite. Enhancement of absorption occurs due to increased flow resistivity with increased compression load of fiber. The effect of the per-deformed petiole date palm fibers for the prepared composite with low fibers load (10% volume fraction) enhanced the sound absorption; as shown in Figure (7), also it was show that at the low frequencies (less than 700 Hz) the value of the sound absorption coefficient for this samples does not depend on the compression loads. It indicates that the absorption increases as impinged wave has to go long way through the material and losses its energy. So it can be noticed from the Figures 8, 9 and10 that the absorption coefficient is slightly increased with all frequencies range with the increased compression load for all the prepared composites having fibers load larger than (10%) from volume fractions. These results denote that absorber prepared with limited compression load and small thickness has a small effect on the absorption of date palm fiber. However increased compression load can be a useful factor for enhancing the absorption this effect due to increased density and flow resistivity of the material with the increasing compression loads. Moreover compression makes the pore of the compressed media small that causes the large frictional effect on sound energy when sound is transmitted in the fluid part of the porous media [25, 26]. Otherwise, there will be a probability of sound waves to be reflected by congested material surface rather than absorption due to compact material [9].

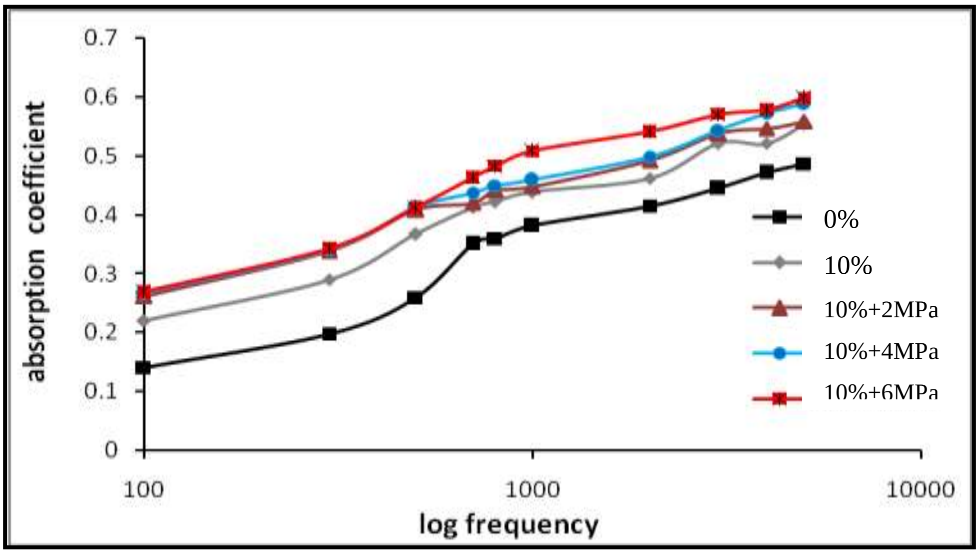


Figure (7): Sound Absorption coefficient versus frequencies of pure polyester and (polyester 10% petiole date palm fiber) composite as a function of compression load.

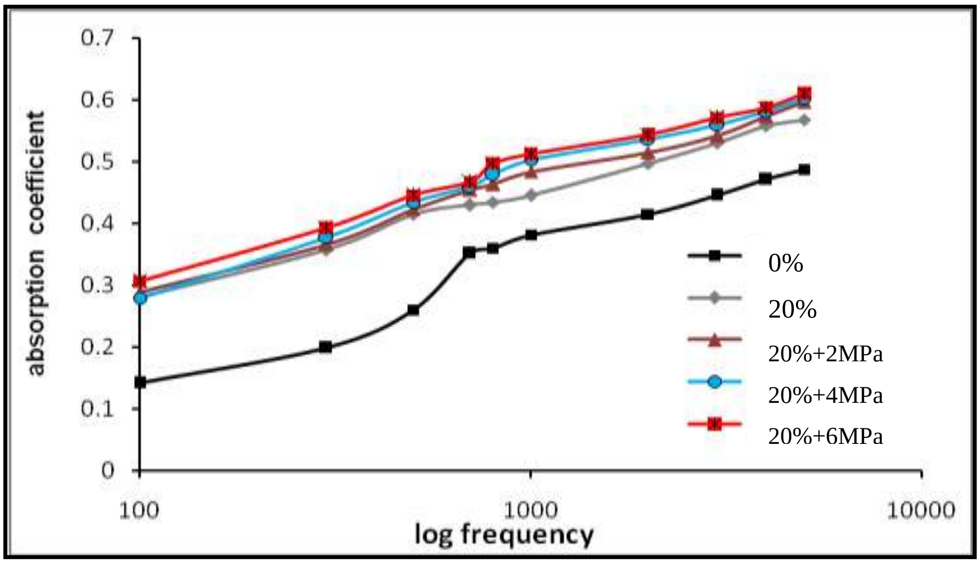


Figure (8) Sound Absorption coefficient versus frequencies of pure polyester and (polyester 20% petiole date palm fiber) composite as a function of compression load.

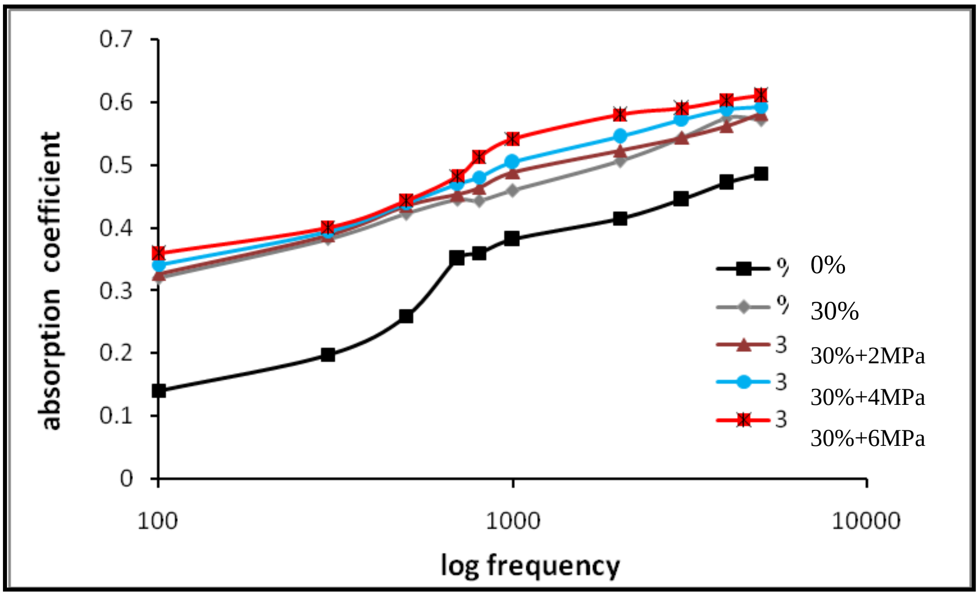


Figure (9) Sound Absorption coefficient versus frequencies of pure polyester and (polyester 30% petiole date palm fiber) composite as a function of compression load.

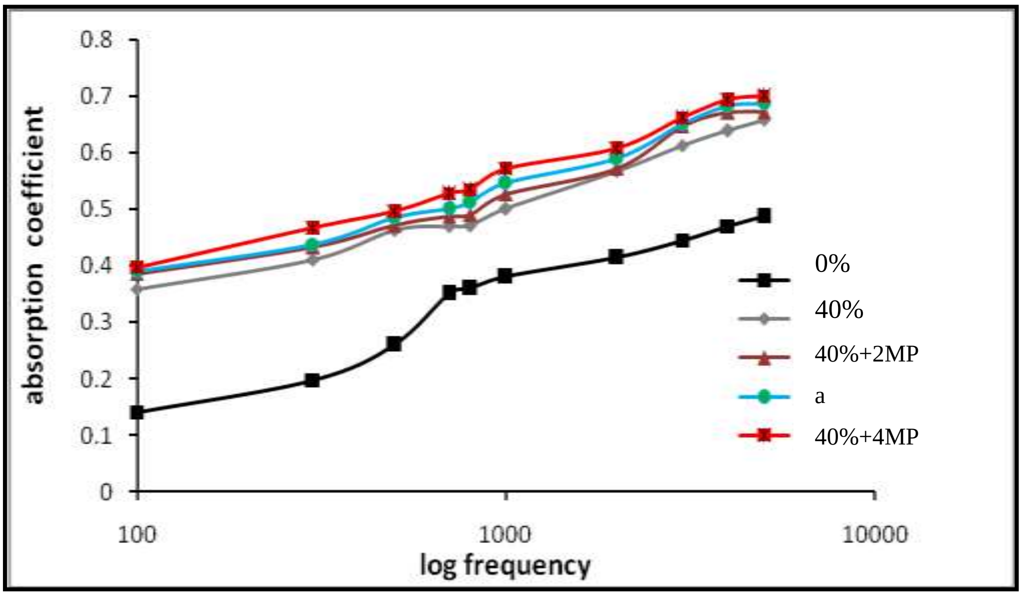
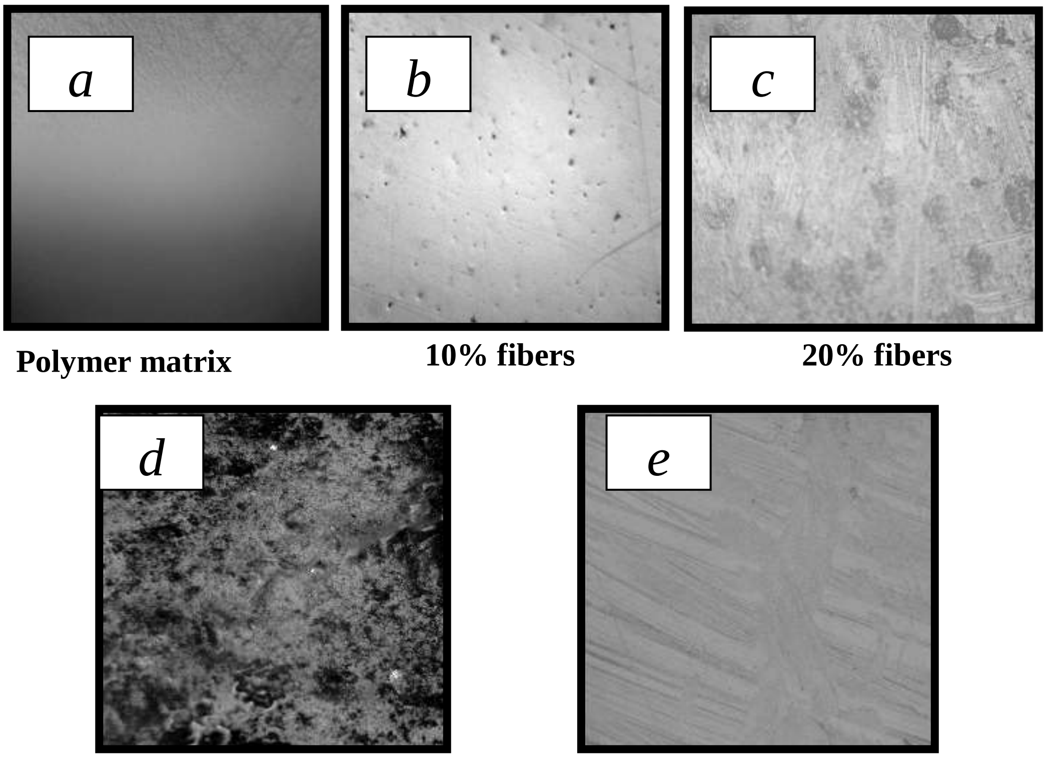


Figure (10): Sound Absorption coefficient versus frequencies of pure polyester and (polyester 40% petiole date palm fiber) composite as a function of compression load.

Morphological study of composites

In order to evaluate the changes in surface morphology and fractured surface of petiole date palm fiber- polymer composite specimens, these were subjected to optical microscopic studies these micrographs on comparison clearly show the difference in the surface morphology of the polymer composite, which depends upon the percent date palm fiber loading as shown in Figure 11 (a ,b, c and d) these micrographs also showed that there was intimate mixing of the fiber with polymer matrix. The effect of pre-deformed petiole date palm fibers by compressive load (6MPa) on fractured surface morphology are shown in Figure 12 (a, b ,c, d, e, f, g, and h) morphological results clearly show that morphological changes take place in fractured surface depending upon the bonding between the varying loading of fiber and the polymer resin matrix as well as on the compressive load, the microscopic fracture surface features show there is change in fracture mode from brittle manner of prepared composite have lower fiber loading (10% or 20%) to ductile fracture surface for high fiber loading (30% or 40%).

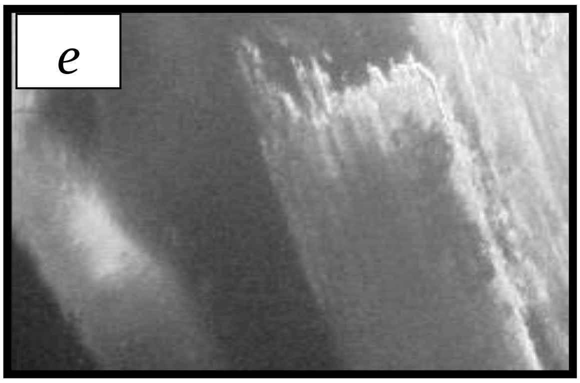


Polymer matrix **10% fibers** **20% fibers**

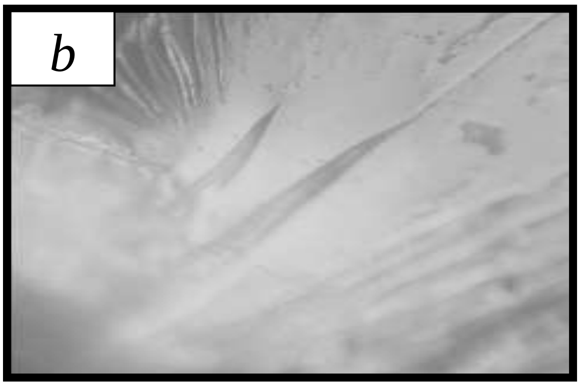
30% fibers **40% fibers**

Figure(11) Surface morphology of polyester-composite as a function of Petiole date palm fiber content. 200x

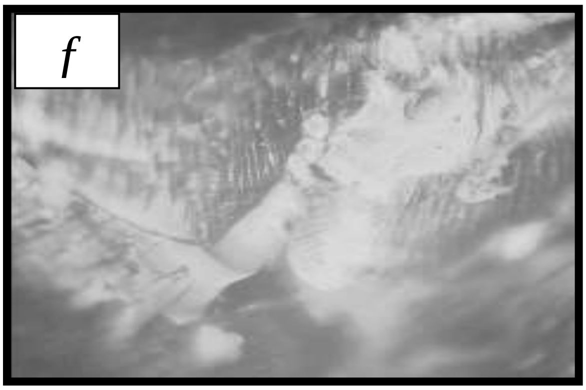
10% fiber un-deformed



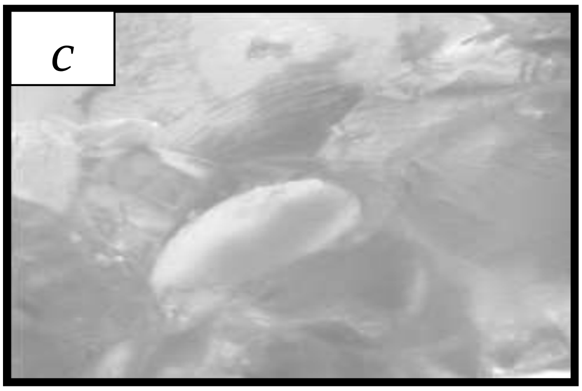
10% fiber per-deformed



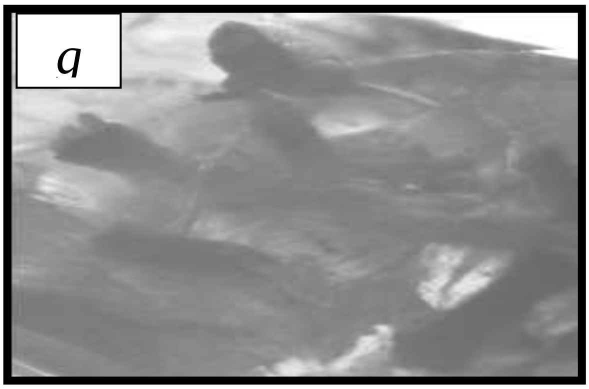
20% fiber un-deformed



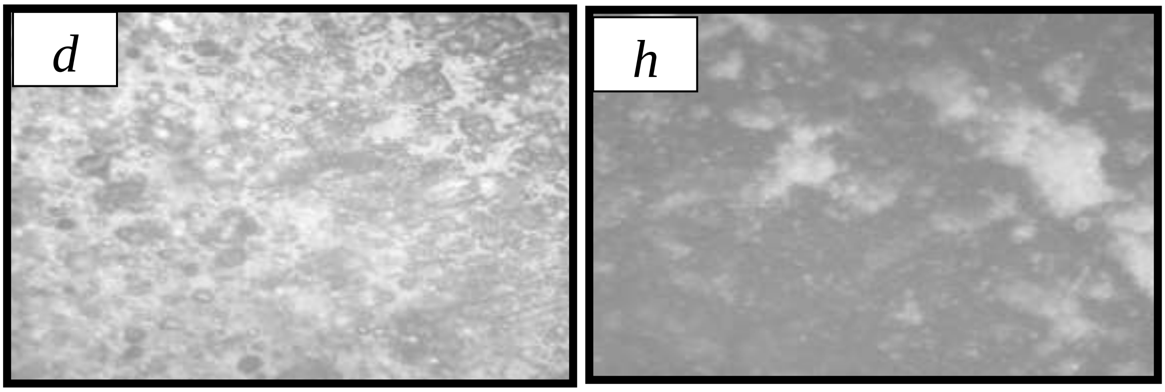
20% fiber per-deformed



30% fiber un-deformed



30% fiber per-deformed



40% fiber un-deformed **40% fiber per-deformed**

Figure. (12): Fractured Surface morphology of polyester-composite as a function of Petiole date palm fiber content (a,b,c,d un-deformed fibers)(e,f,g,h per-deformed fibers). 200x

CONCLUSIONS

In this research it was chose the petiole palm fiber with length (2-3mm) and per-deformation under compression load as a filler in preparation polymer composite, the properties of these composites were investigated as a function of compression load for the petiole palm fibers and it was concluded the following items:-

1. The mechanical properties and the (thermal and acoustic) insulation properties for the entire prepared composite were found to be higher than the parent polymer matrix.
2. The pre-deformation of petiole palm fibers improves the mechanical properties and the (thermal and acoustic) insulation properties for the entire prepared composite.
3. Increasing the compression load of petiole palm fibers increased the mechanical and (acoustic and thermal) insulation properties.
4. The sound absorption coefficient values at low frequencies (less than 700Hz) does not depend on the compression loads for the samples reinforced by low fibers load (10% from volume fraction).
5. The highest values of tensile strength and hardness reach to 119 MPa and 160 respectively for the prepared composite reinforced by pre-deformation of petiole palm fibers under compression load equal to 6 MPa.

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