Effect of Reinforced System by Palm Fibers on the Mechanical and Insulation (Thermal and Acoustic) Properties for Polymer Composite Materials

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ABSTRACT

The research aims to prepare composite materials of unsaturated polyester resin reinforced by palm fiber extracted from different locations (Trunk, Petiole (bases leaflet date palm tree), Rachis and Panicle) of the palm tree in Iraq. The study included the effect of fiber length and their location within the plant as well as the percentage of the volume fraction (0%, 10%, 20%, 30%, and 40%) on the mechanical properties, thermal and acoustic insulation for all the samples prepared.

The results showed that mechanical as well as the thermal and acoustic insulation properties increase with increased the volume fraction for all kinds of the date palm fibers, whereas decrease with increased fiber length also those properties depend on the natural of the date palm fibers as the following sequence (samples reinforced by petiole fibers > samples reinforced by trunk fibers > samples reinforced by rachis fibers > samples reinforced by panicle fibers).

Keywords: palm fibers, thermal & caustic insulation, Unsaturated Polyester.

دراسة تأثير نظام التدعيم بألياف النخيل على الخواص الميكانيكية والعزل الصوتي والحراري لمواد متراكبة بوليمرية

الخلاصة

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يهدف البحث الى تحضير مواد متراكبة من راتنج البولي استر غير المشبع المدعم بالياف النخيل التي استخرجت من مواقع مختلفة (الجذع ، الكربة، ،نصل السعفة، والعثك) من شجرة النخيل في العراق. تتضمن الدراسة تأثير طول الالياف ومواقعها ضمن النبتة علاوة على نسبة الكسر الحجمي المختار (40%,30%,20%,10%,0%) على الخواص الميكانيكية والعزل الحراري والصوتي ولكافة العينات المحضرة .

بينت النتائج ان الخواص الميكانيكية وكذلك العزل الحراري والصوتي تزداد مع زيادة الكسر الحجمي لكل انواع الياف نخيل التمر في حين تتناقص هذه الخواص مع زيادة طول الليف وان الخواص الميكانيكية والعزل الحراري والصوتي للعينات المحضرة تعتمد على طبيعة الياف النخيل وعلى الترتيب التالي (الياف كربة،الياف جذع،الياف عثك والياف الساق).

INTRODUCTION

Present day technology requires materials with combination of properties that cannot be met by the convertible classes of material metals, ceramics and polymers. As a result engineers are compelled to search for alternative materials to meet the complex service requirements for today's applications. Amongst the desired material properties requirement are: low density, strong, abrasion and impact resistant and are not easily corroded [1]. These material property combination and ranges have been met and are yet being extended by the development of composite materials. The development of polymer composites from renewable raw materials has been increased considerably during the last few years [2-3].The use of natural fibers ,derived from a number of renewable resources, as reinforcing materials in both thermoplastic and the rmoset matrix composites provides positive environmental benefits with respect to ultimate disposability and best utilization of raw materials [3-5]. The most importance of natural fillers over traditional reinforcing materials such as (synthetic fibers glass fiber, carbon fiber etc). are their specific strength properties, easy availability, light weight, ease of separation, enhanced energy recovery, high toughness, non-corrosive nature, low density, low cost, good thermal properties, reduced tool wear, reduced dermal and respiratory irritation, less abrasion to processing equipment, renewability and biodegradability[4-8].

These bio-fibers are especially being required since the production of composites using natural substances as reinforcing fillers is not only inexpensive but also able to minimize the environmental pollution caused by the synthetic fibers, enabling these composites to play an important role in resolving future environmental problems.

Composite materials are materials having two or more distinct phases such that a better combination of properties is achieve [9-10]. The constituents must be chemically and physically dissimilar and separated by a distinct interface. The composite consists of a matrix, which is continuous and surrounds the filler, which provides the reinforcement such that the resulting composite property is a function of the properties of both the matrix and filler [9-11]. The properties of palm fiber mainly depend upon their chemical composition. Chemical composition of fibers depends on various factors; it varies with the geographic location, climate, type of fiber, plant part and soil conditions, etc. [12]. Date palm fibers may provide better insulation when compared to glass fibers against noise and heat (low thermal conductivity) in application such as automotive door/ceiling panels and panels separating the engine and the passenger compartment. It is worth mentioning that one of the important functions of mesh fibers is to protect the date palm stem from the surrounding high temperature environment [13].

Other study was carried out in developing natural fibers for sound absorption application (Nor,etal 2004[14], Dias and Monaragala 2006[15], Dias etal 2007[16], Ersoy, S, and H. Kucuk 2009[17]).The absorption coefficient is a measure of absorption power of the certain material, that is defined as the ratio of the sound energy absorbed by a surface (W_{abs}) to the sound energy incident upon that surface(W_{inc}) .[18].

$$\alpha = W_{abs}/W_{inc} = (W_{inc} - W_{ref}) / W_{inc} \quad \text{.....(1)}$$

Where:

α= sound absorption coefficient

W_{ref} = the sound energy reflected from the surface

The absorbed sound energy can be determined in accordance with the equation:

$$W = \bar{I} \times S \qquad \text{........ (2)}$$

Where: $\bar{I}$`=the averaged sound intensity at the measurement surface

S= area of the measurement specimen.

The incident sound energy in diffuse sound field can be determined in accordance with the equation:

$$W_{inc} = (p_{rms})^2 \times S/4\rho c \qquad \text{......... (3)}$$

Where : p_{rms} = the averaged root mean square sound pressure at the measurement surface.

Replacing equations (2) and (3) in (1) we get:

$$\alpha = \bar{I} \times 4\rho c/(p_{rms})^2 \qquad \text{..............(4)}$$

If the sound pressure and the sound intensity are expressed by sound pressure level and intensity level, respectively, the equation (4) becomes [19]:

$$\alpha = \text{anti log} \, [(L_I - (L_\rho - 6))/10] \text{..........(5)}$$

Where **L_I=** the averaged sound intensity level at the measurement surface, L_ρ = the averaged sound pressure at the measurement surface.

The main objective of this study is to analyze the effect of different factors on the mechanical, thermal and acoustic insulation properties of date palm fibers reinforced polymeric matrix.

EXPERIMENTAL

Material

Unsaturated polyester resin (UP) was used as matrix material, supplied by (SIR) Saudi company. Was a viscous liquid, transparent at room temperature? Its one types of polymers 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. The* properties of resin which was used are shown in Table (1).

Palm fibers were collected locally from the Date trees obtained mainly from Baghdad farmer in middle of Iraq. The fibers were taken from the four parts of date palm (trunk, petiole (bases leaflet date palm tree), Rachis and panicle) as shown in Figures (1, 2, 3, 4) respectively.

As a first step the fibers were washed thoroughly with detergent powder in order to remove dust and mud. After these fibers were soaked in hot distilled water for 2h, dried for 72h 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, this fiber was used in three forms as shown below:

1. Short fiber reinforcement: date palm fibers were chopped into (2-4) mm length these fibers were used as short fibers.
2. Medium fiber reinforcement: petiole (bases leaflet date palm fibers were chopped into (10-20) mm length these were used as medium fiber.
3. Long fiber reinforcement: Petiole date palm fibers were chopped into (30-40) mm length .these fibers were used as long fiber.

Chemical treatments

Chemical treatments were employed for surface modification of date palm fibers. Fibers were soaked in 5% sodium hydroxide (NaOH) for 48hours 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 desiccator's before preparation of composite.

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. The inner face of the mould was packed with a layer of thermal nylon papers made of a polyvinyl alcohol substance, to ensure non adhesion the polyester resin with mould walls thermal silicon was used for joining framers and filling the blanks in the mould. Palm fibers of dimension (2-4 mm) (as well as for other fibers) after proper purification and drying were thoroughly mixed with polyester resin by different fibers loading (10, 20, 30, 40%) in terms of volume fraction, then the mixture was poured into the mould and allowed to cure for 24h at room temperature (27°C). All the specimens were then post cured in an oven at 55°C for 2h by using electrical oven. Composite sheets of size ($240\times240\times5\ mm^3$) were prepared for acoustic insulation, then the sheets cut off and machined according to standard specifications to produce samples conforming for mechanical (tensile and hardness) and thermal conductivity test, all these tests were carried for all the prepared samples.

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 strain rate of the order of 10mm/min. tensile stress 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 (ASTM DIN-53505) standard is used for hard polymer materials with specimen dimensions of (40mm diameter and 5mm thick).

Thermal conductivity test:

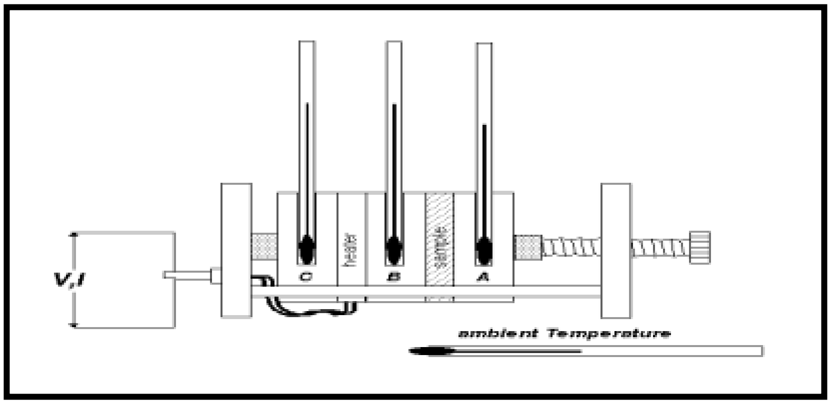
For the measurement of thermal conductivity the apparatus used was a modification of the standard Lee's disk method. A diagram of the apparatus is shown in Figure (4). This consists of three copper plates (A, B and C) and a 6W electrical plate heater of the same diameter as the copper plates. The sample to be studied was cut to the same diameter as the copper plates (40) mm and to a thickness of approximately (5) mm. A value for the thermal conductivity of the specimen (K) of thickness d and radius r was calculated from the following [20]:

$$K=[ed/2\pi r^2(T_B-T_A)]\times[a_s(T_A+T_B)/2+2a_AT_A] \quad \ldots(6)$$

Where e is given by:

$$e=VI/[a_AT_A+a_s(T_A+T_B)/2+a_H(T_B+T_C)/2+a_B T_B+a_C T_C] \quad \ldots(7)$$

$\mathbf{a_A,a_B,a_C}$ 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, TB and T_C are the temperatures of the discs A.B and C above ambient. (V) is the potential difference a cross the heater and (I) is the current which flows through it. K = thermal conductivity in (w / m.˚C).



NOISE ABSORPTION COEFFICIENT

The Noise absorption coefficient (NAC) measurement was carried out according to ASTM E-336. NAC 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. The microphone positions are located at 60 cm in front of the test specimen.

RESULTS AND DISCUSSION

Mechanical properties

The investigation of mechanical properties of composites is one of the most important techniques in studding the behavior of composite materials. It has been proved to be the most effective method to study the behavior of polymer composite materials under various conditions of tension stress of fiber composites and its role in determining the mechanical properties. Mechanical properties of fiber reinforced composites depend on the nature of the fiber. 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.

Optimization of date palm fiber reinforced polyester composites has been done by evaluating mechanical properties such as tensile strength and hardness. The tensile strength values of date palm petiole fiber reinforced polyester composites for different lengths, are given in Figure (6). This figure shows the short fiber (2-4 mm) gives higher tensile strength value compare to the larger fiber lengths, and also shows the tensile strength value increases with increasing palm fiber content, the tensile strength values seems to be reach to stable state when the volume fraction of the fibers increases to higher than 30% for the long and medium fibers composites. Figure(7) shows the young modulus of polyester composites increases with increasing palm fiber content, the short fiber composites gives higher modulus value compare to the larger fiber length. The elongation of the composites decreases with increasing the volume fraction of palm fiber as shown in Figure (8). Figure (9) show the shore-D hardness of polyester- composite as function of date palm fibers content for three different lengths. The shore hardness of the composite is slightly increases with increasing fibers content, the short fiber composite gives higher hardness values. In general, this increase of shore hardness of the composites is due to date palm fibers which are higher increase with the shortest fibers because high compaction and homogeneity distribution of these fibers [21].

From these results it is clear that short fiber (2-4 mm) reinforcement is more effective than long (30-40 mm) and medium fiber (10-20 mm) reinforcement. This may be due to larger surface area and more fiber-matrix interaction and more homogenous of randomly distribution in case of short date palm fiber reinforced pomposities. According to Baiardo ET. Al [22].

The mechanical properties of short fiber reinforced composites are expected to depend on (i) the intrinsic properties of matrix and fibers, (ii) aspect ratio, content, length distribution and orientation of the fibers in the composite and (iii) fiber-matrix adhesion that is responsible for the efficiency of load transfer in the composites.

Fiber type

The effect of fiber type which was taken from the four parts of date palm (Trunk, Petiole, Panicle and Rachis) on mechanical behavior of polyester composite was taken in consideration. Figures (10) and (11) illustrate the effect of fiber contend and fiber type on the tensile strength and tensile modulus of polyester composite respectively. As shown, there was significant improvement in tensile strength and tensile modulus as the fiber content increased. The variation trend of tensile strength and modulus were similar for four parts of date palm fibers location. The highest tensile strength and modulus of polyester composite were achieved by using petiole fiber, then trunk fibers, next panicle fibers finally rachis fibers which gives the lower values. Figure (12) showns the elongation of foregoing composites decreased as fiber content increased. The lower elongation values were achieved by using Petiole fiber. Figure (13) shows the variation in shore-D hardness values of polyester composite with palm fibers concentration in the composites. Hardness gradually increased with palm fibers contend for four parts of date palm fibers location. The highest hardness value achieved by using petiole fibers, whereas the rachis fiber given the lower values. The increase of hardness is due to the brittle nature of lignocelluloses fibers [3]. As well as the petiole fiber has a higher aspect ratio, which yielded better mechanical properties of the composite. Also lower lignin content of petiole gave rise an increase of the hydrophilic character of the fiber [23]. As a consequence, the wettability of the fiber surface will be increased. This difference can be explained from the stronger interaction developed by the carboxylic groups created on the petiole fibers [16]. These findings are consistent with opinions stated by Sbiai et al [24].

Thermal conductivity

The thermal conductivity of many engineered materials depends upon the volume fraction of different phases and their connectivity. In order to achieve good thermal behavior of polyester-composite, a variety of studies are ongoing to find ways to use to date palm fiber in place of synthetic fibers in thermal insulation applications. Therefore the composite samples which were prepared for thermal conductivity test was depend upon the following (i) the length of fibers which was taken from petiole date palm location as shown in Figure (14), (ii) the fibers location which was taken from four parts of date palm see Figure (15). It was observed that the thermal conductivity for all these composite samples decreases with increasing the palm fibers content, the composites reinforced by short fiber gives lower value of thermal conductivity compare to that reinforced by larger fiber length, and the thermal conductivity values of shortly fiber composites seem to be reach to stable stats when the volume fraction of the fiber increases to higher than 30%. The effect of fiber type on thermal conductivity of composite samples was shown in Figure (15) the lower thermal conductivity values of the prepared composite were achieved by using petiole fiber, whereas the rachis fiber gives the higher values of thermal conductivity. 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 nature of date palm fibers as a hollow tubular structure[13], which leading to 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 fiber palm 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 the phonons will suffer obstruction in there motion because the medium presence is different from the first medium, which will lead to decrease thermal conductivity values, as well as the thermal conductivity value for the palm fiber is more lower than the polyester matrix, therefore as the load fiber increases the thermal conductivity of the prepared composite decreased.

Acoustic absorption coefficient

The main parameters critical in the determination of the acoustic properties are the acoustic absorption coefficient. Calculation may be performed at single frequencies or as a mean values in 1/3 octave bands. Figure (16) shows the experimental results obtained for pure polyester material and polyester-composite (for four locations parts of date palm all the samples have the same thickness (5mm), the composites sample 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 as a hollow tubular structure(cellular fibers) is expected to yield good reinforcement with high damping properties[13]. Also from this figure it is notice that the rachis fiber composite shows higher absorption coefficient for the range of (400 Hz) until (2500 Hz), compared to other date palm fiber composite. Whereas for the frequency range of more than (2500Hz) the petiole fiber gives higher absorption coefficient. The maximum amount of acoustic insulation (0.757) was shown for rachis fiber composite at the frequency (900 Hz). The results obtained from Figure (16), showing a significant different because there are huge different in natural of fibers which taken from different location for parts of date palm tree, and there are many factors which effective on absorption coefficient such as cell size, porosity, material density and material thickness. Generrally the thicker material exhibits maximum sound absorption coefficient at high frequencies. Ballagh found, the increasing of the bulk sample density will increase also the absorption coefficient, and also found that the absorption coefficient increases with a decrease in fiber diameter [25].

Figures (17,18,19 and 20) show the graphs of the sound Absorption coefficient versus the test frequency for pure polyester and polyester- date palm fiber composites, the fibers was taken from different parts of date palm which were trunk, petiole, panicle and rachis respectively all these graphs was done as a function of loading fibers.

From these graphs it is evident that by increasing the loading fibers of trunk, petiole and panicle fibers, the absorption coefficient increases at all range of frequency, as shown by Figures(17,18 and 19) respectively , so at given frequency the higher amount of sound absorption coefficient was caused by fiber added to composite, whereas from Figure(20) when polyester material reinforced by rachis fiber these composite showed the different reaction against sound waves over a wide range of frequency when frequencies increased sound absorption coefficient increased until it reached to (900 Hz) then the absorption decreases` slowly as frequency increased and reached nearly to stabile state at higher frequencies . Rachis fibers showed the highest power for sound absorbing at low frequency, this behavior in given frequency contributed to the specific characteristic of rachis fibers may be reflecting partial of sound wave at high frequency and absorbing sound waves under (1000 Hz), these results is a good agreement with result obtained by Mohammadali for other material [19].

CONCLUSIONS

1. The mechanical and (thermal and acoustic) insulation properties of unsaturated polyester resin and its composites (polymer reinforce by date palm fiber) were investigated as a function of locations fibers in date palm tree and the content and length of the reinforcing fiber material. The following conclusion can be drawn from those study:
   1- The mechanical and insulation properties of fiber reinforced polymer matrix resin based composites were found to be higher than the parent polymer matrix.
   2- Increasing the volume fraction of the fibers [extracted from different location (Trunk, Petiole, Rachis and Panicle) of data palm tree) into polymer composite material, led to improved mechanical and (thermal and acoustic) insulation properties of prepared composites.

3- The mechanical and insulation properties increase with decreased fiber length in composite material.
4- Petiole fiber reinforced polymer matrix based composites. Exhibited optimum mechanical and insulation properties.
5- The mechanical and insulation properties of prepared composites depend on the natural of the data palm fibers as the following sequence:

Samples Reinforced by Petiole Palm >Samples Reinforced by Trunk Palm >Samples Reinforced by Rachis Palm>Samples Reinforced by Panicle Palm.

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Table (1): **the properties of unsaturated polyester resin (UP) according Product Company.**

Name	Density (gm/cm^3)	Specific Heat (J/Kg.k)	Fracture Toughness (MPa.m$^{0.5}$)	Tensile strength (MPa)	Percent Elongation (EL%)	Modulus of elasticity (GPa)
polyester Resin	1.2	920-710	0.6	89.7-41.4	< 2.6	4.11-2.06

(a) (b)

Figure (1): (a) data palm Trunk, (b) primary clean up trunk fibers.

(a) (b)

Figure (2): (a) data palm Petiole, (b) primary clean up petiole fibers.

Figure (3): (a) data palm Panicle

Figure (4):(b) data palm rachis.

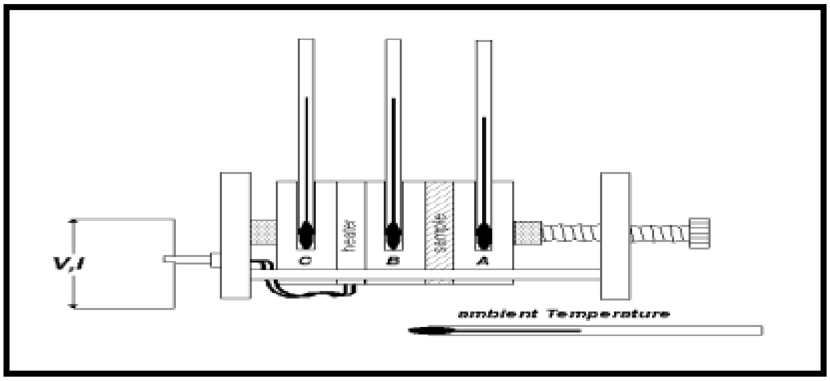

Figure (5): L+ees' Disk Apparatus (schematic)[13].

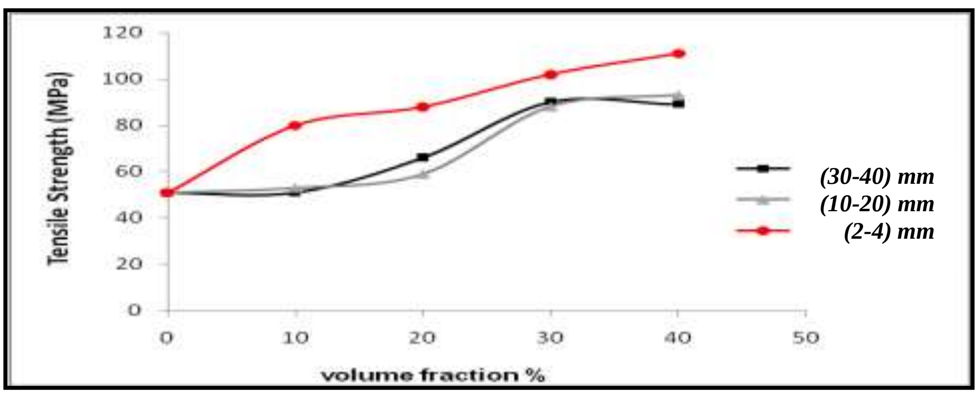

Figure (6): Tensile strength of polyester- composite as a function of date palm fiber content for three different lengths.

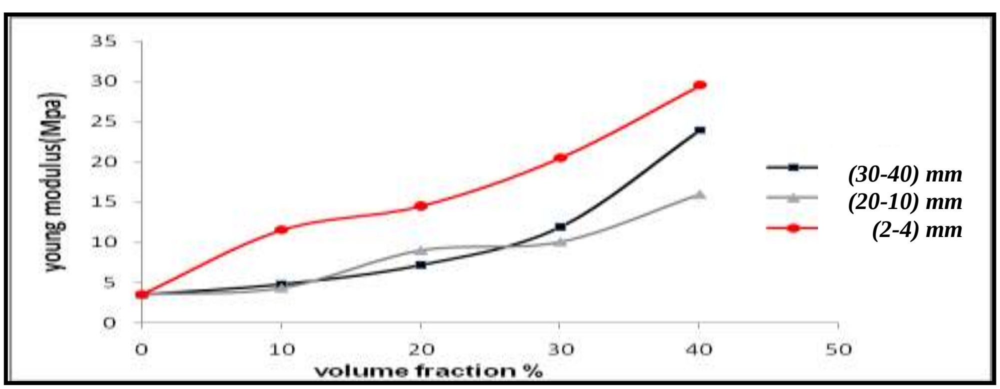

Figure (7): Young modulus of polyester- composite as a function of date palm fiber content for three different lengths.

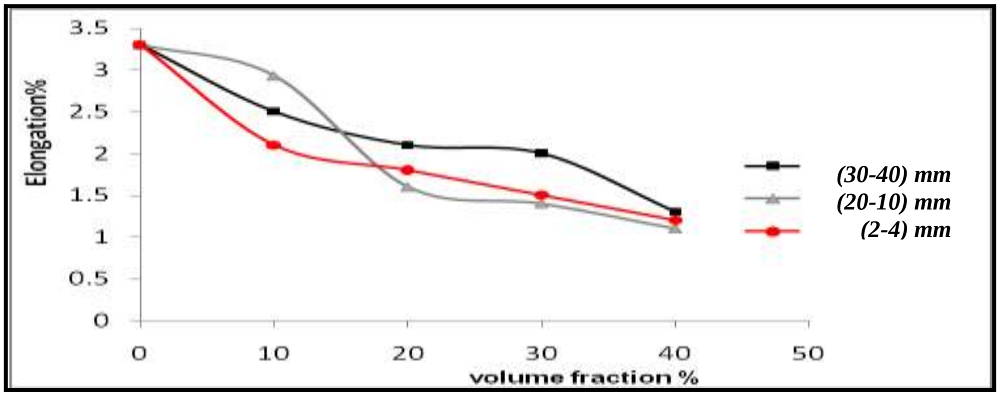

Figure (8): Elongation of polyester- composite as a function of date palm fiber content for three different lengths.

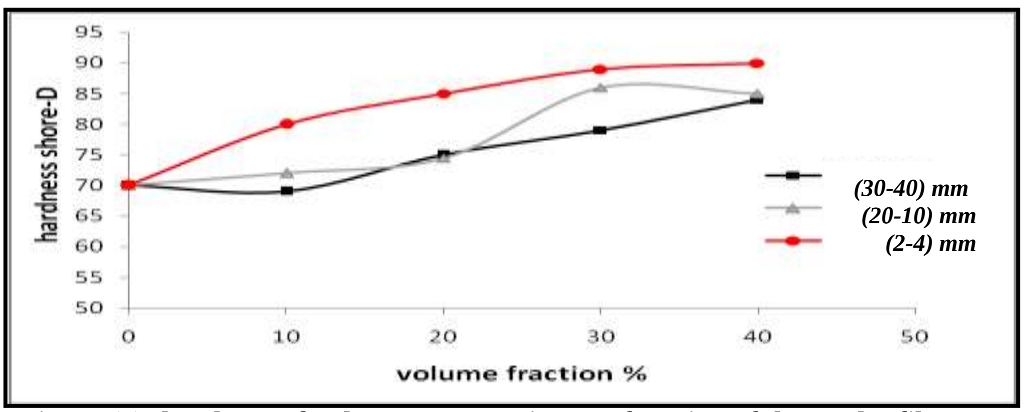

Figure (9): hardness of polyester composite as a function of date palm fiber content for three different lengths.

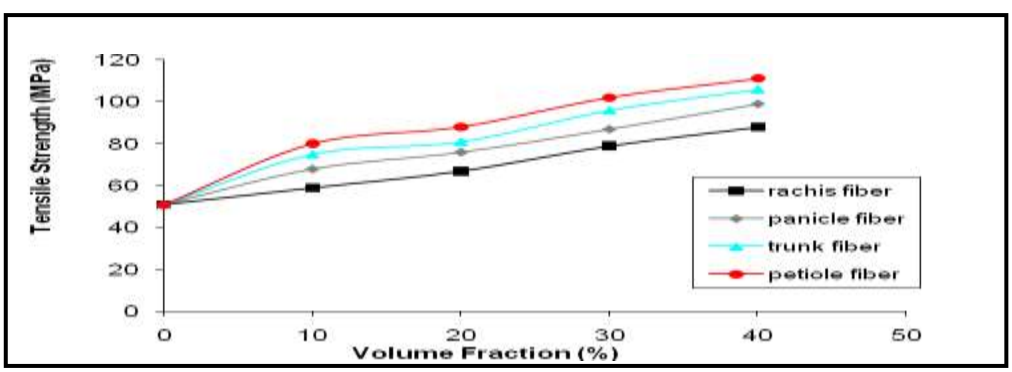

Figure (10): Tensile strength of polyester- composite as a function of date palm fiber content for four parts of date palm location.

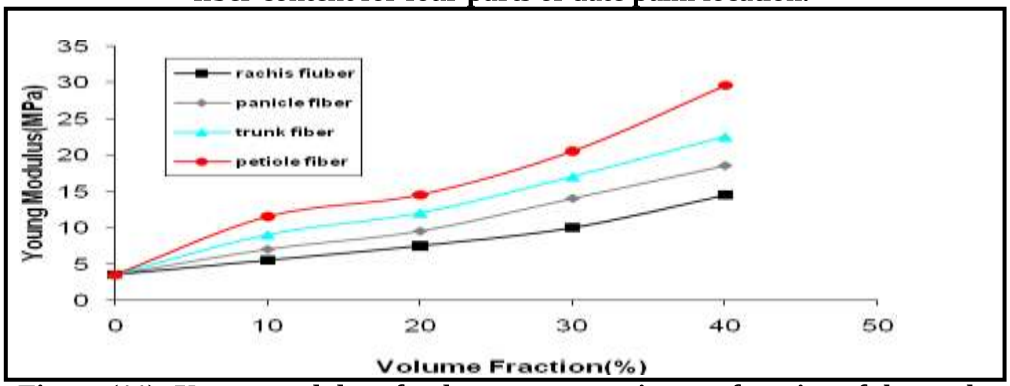

Figure (11): Young modulus of polyester- composite as a function of date palm fiber content for four parts of date palm location.

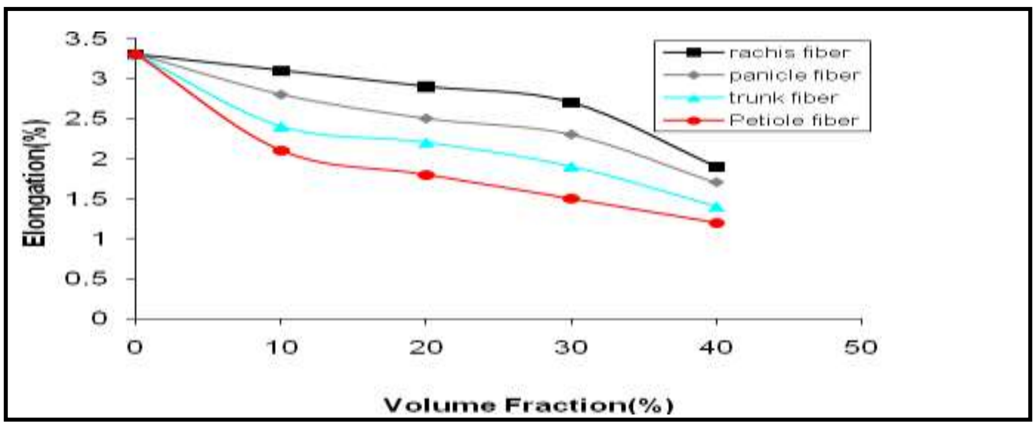

Figure (12): Elongation of polyester- composite as a function of date palm fiber content for four parts of date palm location.

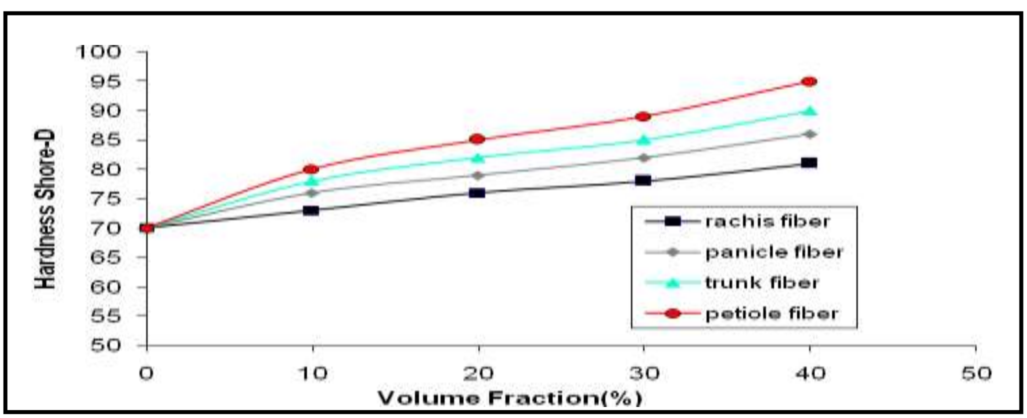

Figure (13): Hardness of polyester- composite as a function of date palm fiber content for four parts of date palm location.

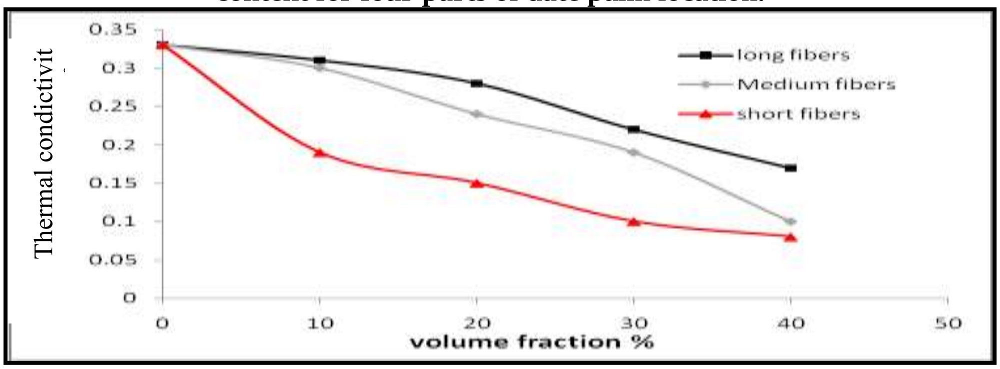

Figure (14): Thermal conductivity of polyester- composite as a function of date palm fiber content for three different lengths.

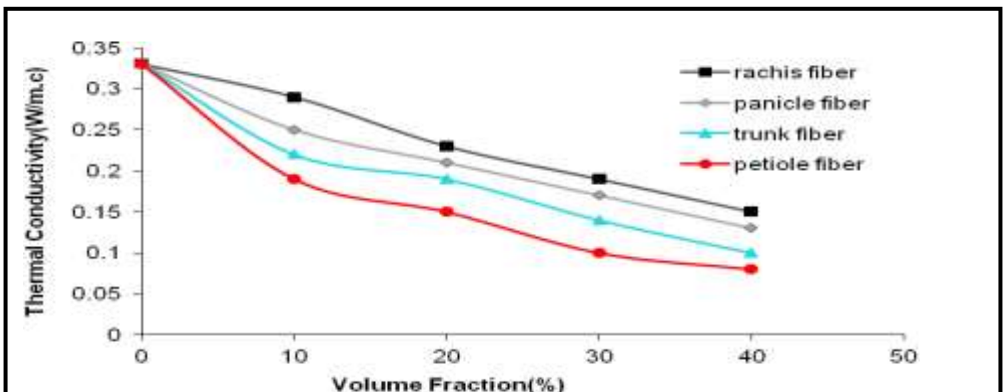

Figure (15): Thermal conductivity of polyester- composite as a function of date palm fiber content for four parts of date palm location.

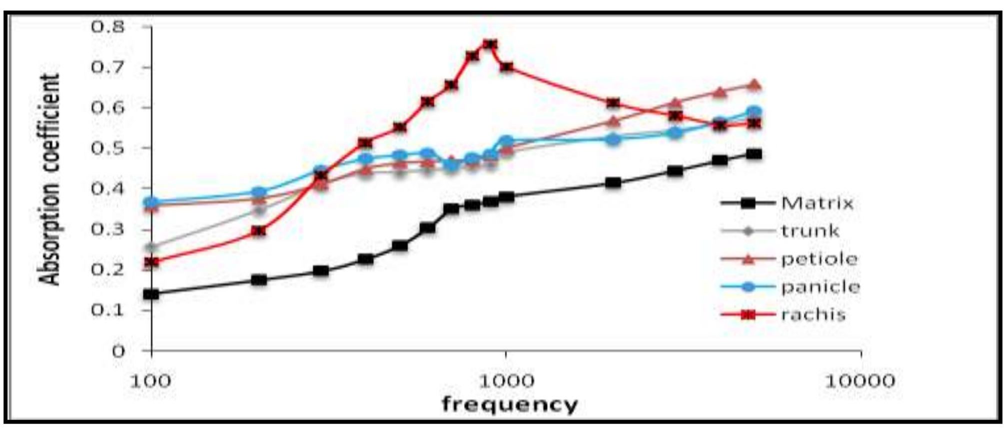

Figure (16): Sound Absorption coefficient versus frequencies of pure polyester and polyester- palm fiber composite as a function of date palm fiber content for four parts of date palm location.

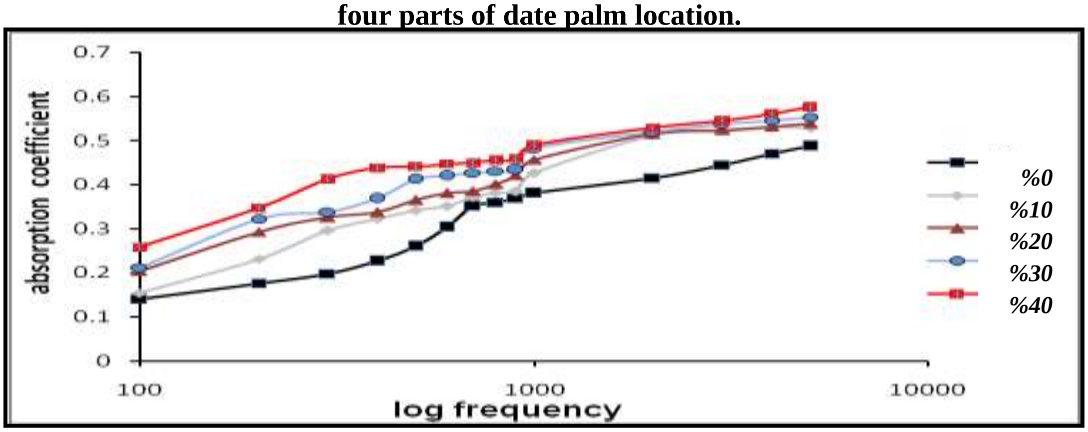

Figure (17): Sound Absorption coefficient versus frequencies as a function of loading trunk fibers, for polyester – palm fiber composite.

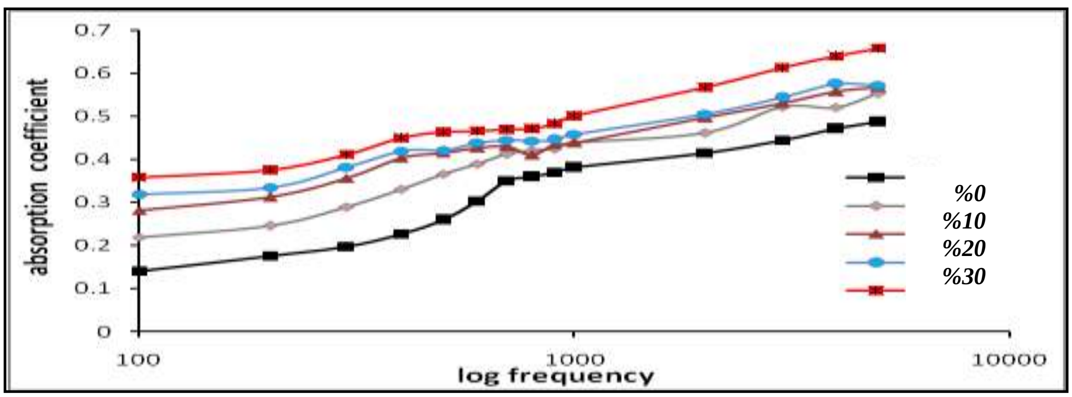

Figure (18): Sound Absorption coefficient versus frequencies as a function of loading petiole fibers, for polyester – palm fiber composite.

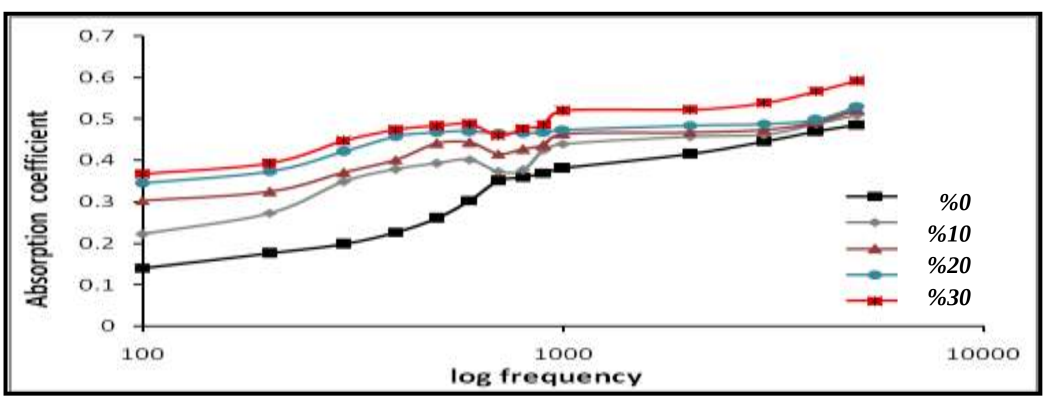

Figure (19): Sound Absorption coefficient versus frequencies as a function of loading panicle fibers, for polyester – palm fiber composite.

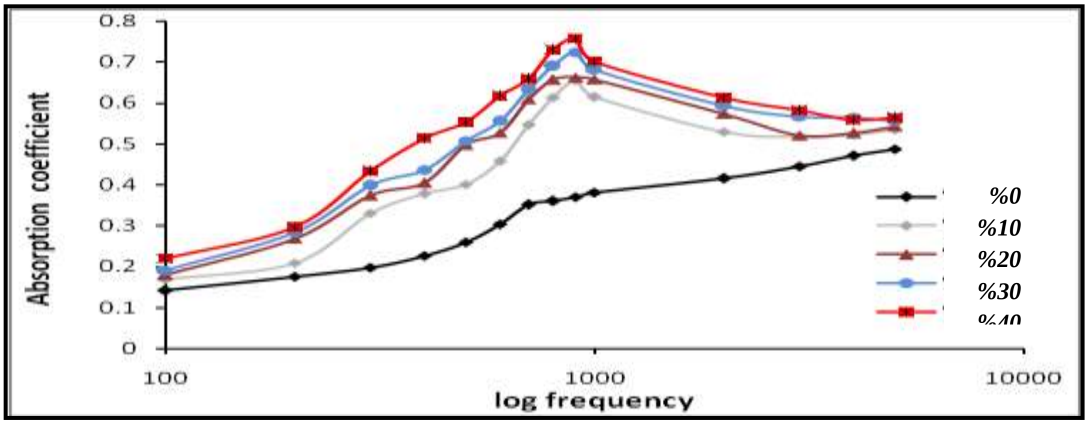

Figure (20): Sound Absorption coefficient versus frequencies as a function of loading rachis fibers, for polyester – palm fiber composite.