Iraqi Journal of Physics, 2016 *Vol.14, No.31, PP. 138-147*

Preparation and studying of some properties of polymer composites reinforced with natural and artificial fibers

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Abstract

This work concerns the thermal and sound insulation as well as the mechanical properties of polymer matrix composite reinforced with glass fibers. These fibers may have dangerous effect during handling, for example the glass fibers might cause some damage to the eyes, lungs and even skin. For this reason the present work, investigates the behavior of polymer composite reinforced with natural fibers (Plant fibers) as replacement to glass fibers. Unsaturated Polyester resin was used as matrix material reinforced with two types of fibers, one of them is artificial (Glass fibers) and the other type is natural (Jute, Fronds Palm and Reed Fibers) by hand lay-up technique. All fibers are untreated with any chemical solvent. The Percentage of mixing was (90 wt. %) of the matrix while the weight fraction of each type of fibers was fixed (10 wt. %). The mechanical tests included impact and flexural strength tests. The results showed that the impact strength and flexural strength of the composites reinforced with Jute fibers is higher than that of Glass fibers and other natural fibers. The coefficients of thermal conductivity of the composites were measured by Lee's disc apparatus, the results show that the thermal insulation of the composite reinforced with jute fibers is higher than that of glass fibers and other natural fibers. The acoustic insulation of the composites reinforced with Jute fibers showed excellent result in insulation compared with glass fibers and other natural fibers.

Key words
Polymer Composite, Unsaturated Polyester resin, Eco-friendly Composite, Natural fibers.

Article info.
Received: Jul. 2016
Accepted: Sep. 2016
Published: Dec. 2016

تحضير ودراسة بعض الخواص لمتراكبات بوليمرية مسلحة بالياف طبيعية وصناعية

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الخلاصة

أهتمت العديد من البحوث في دراسة الخواص العزل الحراري والصوتي و الخواص الميكانيكية لمتراكبات بوليمرية مسلحة بالياف الزجاج علما بأن هذه الالياف لها مضار عند التعامل معها فهي قد تضر بالعينين والرئتين وكذلك الجلد لذا ارتأينا اجراء دراسة خواص لمتراكبات البوليمر المقواة بألياف طبيعية (نباتية) كبدائل عن الياف الزجاج ومقارنة خواص كليهما وتحديد النتائج. استخدم راتنج البولي استر غير المشبع كمادة اساس وتم تسلسحه مع نوعين من الالياف، صناعية (الياف الزجاج) وطبيعية (الياف الجوت، وسعف النخيل، والياف القصب) جميع الالياف استخدمت بدون معاملة كيميائية، بواسطة تقنية الصب اليدوي. الكسر الوزني للرتنج كانت 90% نسبة وزنية بينما كان الكسر الوزني لجميع للأياف ثابت وهو 10% نسبة وزنية، الاختبارات الميكانيكية الي تم اجرائها هي اختبار الصدمة بطريقة جاربي واختبار مقاومة الكسر لحساب قيمة مقاومة الصدمة ومقاومة الكسر لهذه المتراكبات، النتائج اضهرت ان المتراكبات المسلحة بالياف الجوت (الطبيعية) لها مقاومة صدمة ومقاومة كسر اعلى من الياف الزجاج والاياف الطبيعية الاخرى. كذلك تم اجراء فحص التوصيلية الحرارية لهذه المتراكبات باستخدام جهاز (قرص لي) واوضحت نتائج اختبار التوصيلية الحرارية بأن العزل احراري للمتراكبات المسلحة بألياف الجوت اعلى من المتراكبات المسلحة بألياف الزجاج وكذلك اعلى من الالياف الطبيعية الاخرى، بينما نتائج فحص العزل الصوتي للمتراكبات المسلحة بألياف الجوت كانت ممتازة مقارنة بالمتراكبات المسلحة بالياف الزجاج وكذلك المتراكبات المسلحة بالاياف الطبيعيه الاخرى.

Introduction

In the past two decades, growing interest for the research in natural fiber composites has increased in extensive scale. The reasons behind increasing of the popularity of bio-composites or natural fiber composites are its abundant availability, competitive quality and their environmental friendliness. Furthermore, the possibility of production of new natural fiber products through injection molding and extrusion has shown the viability to be a future material [1]. Recent researches and developments have shown the interest on the natural fibers. The high technological industries have also shown the interest on the natural fiber like flax, hemp, Jute, coconut and sisal for the production of new products. Natural fiber is an interesting alternative to synthetic fiber for the composite technology. Surprisingly, the natural fibers are cheaper and possess better stiffness in terms of weight compared to synthetic fiber. These fiber products are lighter in weight and environmental friendly [2]. The molding and shaping process of plant fibers requires less energy than molding artificial fiber as well as produced automobiles consume less fuel due to their weight, which not only saves money but also preserve the nature. Furthermore, automobiles made from coconut natural fibers are more comfortable for users than those filled with plastic foam. Therefore, consumers are becoming aware of the environmental benefits and cost effectiveness offered by natural fiber composites [3]. The disadvantages of natural fiber reinforced polymer composites are the incompatibility between the natural fiber and polymer, leading to formation of a narrow and weak interface. This could also lead to the non-uniform dispersion of fiber within the matrix. Also, the processing temperatures of natural fiber reinforced polymer composites are restricted to low temperatures due to the degradability of natural fibers at high temperatures. The hydrophilic nature of fibers leads to high moisture uptake which can lead to low mechanical properties of the composite. The interface formed in natural fiber reinforced polymer composites is relatively weak compared to conventional composite made of glass due to polar and non-polar nature of fiber and polymer, respectively. To overcome this problem, modifications may be used either physical modifications or chemical modifications. All these processes modify the fiber surface, and consequently a better adhesion is attained between phases [3-4] Mohapatra et al. [5] studied the thermal conductivity of palm fibers reinforced with polyester resin. This composite has been prepared in different volume fraction of palm fibers by using hand lay-up technique. The thermal conductivity of composite was determined by using Lee's apparatus. The results show that the thermal conductivity of this composite increased with the increasing of fibers content. Sally et al. [6] studied the physical properties, microstructure and spectroscopic properties of composite material Scanning Electron Microscope and Fourier Transform Infrared Spectroscopy for unsaturated polyester reinforced with Sawdust fibers with three different proportion of volume fraction of fibers (20, 30, 40 Vol.%) by hand lay-up technique. The results showed that the increasing in sawdust volume fraction lead to decreasing in mechanical properties and increasing in thermal and acoustic insulation properties. The present work, aims to compare between the behavior of polymer matrix composites reinforced with synthetic and natural fibers and determine the impact and flexural strengths as well as acoustic and thermal insulation for each composite under study.

Experimental procedure

1. Materials

Unsaturated polyester resin in the form of a transparent viscous liquid at room temperature was used as a matrix which was supplied from Sika Co. / Saudi Arabia. It is one kind of thermosetting polymers that convert from liquid to a solid state by adding the hardener Methyl Ethyl Keton Peroxide to it. The rate of maxing for unsaturated polyester was 98%wt. will for hardener was 2%wt. This resin used to reinforce two types of fibers, artificial fibers represented by Glass fibers and natural fibers represented by Jute, fronds Palm and Reed fibers.

2. Samples preparation

All casts were prepared by using glass molds in hand lay-up technique. Before casting process, polymer sheets (transparent paper) were prepared to cover the surface of the mold to prevent any interaction between glass surface of mold and composites materials. The outside of molds were surrounded with sticking tape – Fablon – to prevent the leakage of polymer materials. The mold's size is $(24\times24\times1)\,\text{cm}$, this size of samples were prepared to perform sound insulation test, then the samples were cut according to international standard for the mechanical tests. The samples of Charpy impact test were cut via (ISO-179) while the samples of flexural strength were cut by (ASTM-D790). Finally the samples of thermal conductivity test were cut according to the specification of instrument (Diameter 40mm – Thickness 10mm). It is important to illustrate that the symbols of the composites under work are shown in Table 1.

Table 1: The symbols of each type of materials under work

Symbol	Type of material
P	Pure (Unsaturated polyester resin)
F.C	Fronds Palm composite
R.C	Reed Composite
J.C	Jute composite
G.C	Glass composite

Test procedure

1. Impact test

The impact strength of specimens was determined by using Charpy impact tester according to ISO-179 standards with dimensions of (length 55mm, thickness 10mm, width 10mm) without notch, Fig. 1 Shows the samples before carrying out this test. In each case three specimens were tested to obtain average value. The impact strength of composites specimens was calculated in unit kJ/m^2 according to [7]:

$$\text{I.S.} = \frac{U_c}{A}\ \text{kJ/m}^2 \qquad (1)$$

where U_c is the energy required to fracture the sample while A is the cross sectional area of the sample.

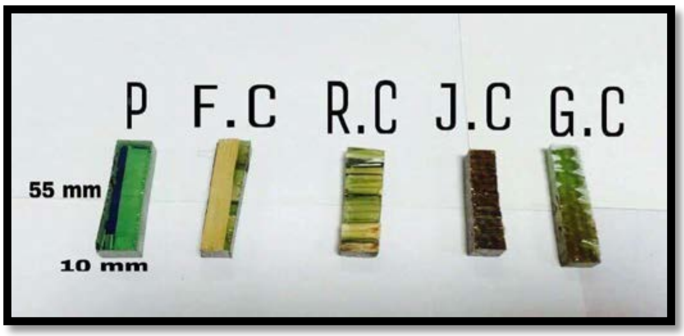

Fig. 1: Impact test samples before test.

2. Flexural strength test

Flexural strength test was performed using 3-point bending method according to (ASTM D-790) procedure with dimensions of (length 100mm, thickness 10mm, width 10mm) as in Fig. 2. The specimens were tested at a crosshead speed of 2 mm/min, at a temperature 25°C. In each case three samples were taken and average value was recorded, and the flexural strength of composite specimens was calculated via [8]:

$$F.S. = \frac{3pL}{2bd^2}(MPa) \qquad (2)$$

where

p : The applied load (N).

L : The distance between two supports (mm).

b : The width of sample (mm).

d : The thickness of sample (mm).

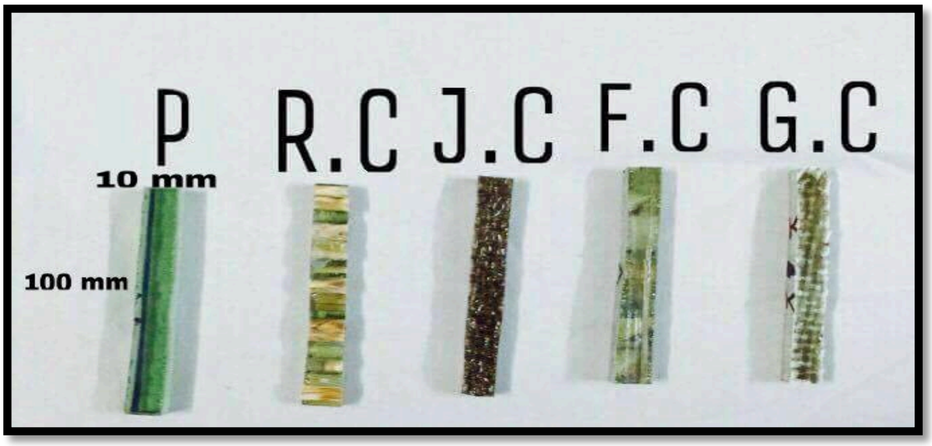

Fig. 2: Flexural strength samples before test.

3. Thermal insulation

To measure the coefficient of thermal conductivity for all samples, by using Lee's disc device. The sample of thermal conductivity was cut according to specification of instrument (Diameter 40 mm – Thickness 10 mm). as Fig. 3.

The value of (e) is calculated by the Eq. (3):

$$IV = \pi r^2 e(T_A + T_B) + 2\pi r e\left[d_A T_A + \frac{1}{2}ds(T_A + T_B) + d_B T_B + d_C T_C\right] \qquad (3)$$

(e) Represents the amount of heat (heat energy) through unit area per second.

(I) Is the current value through the electrical circuit.

(V) Is the applied voltage.

For calculation the coefficient of thermal conductivity (K), the following equation is used:

$$K\left(\frac{T_B - T_A}{T_A}\right) = e\left[T_A + \frac{2}{r}\left(d_A + \frac{1}{4}ds\right)T_A + \frac{1}{2r}dsT_B\right] \qquad (4)$$

where

T: temperature of the three discs A, B and C (°C).

d: thickness of sample (mm).

r: radius of sample (mm).

Fig.3: Thermal conductivity samples.

4. Acoustic insulation

Acoustic insulation was measured using the locally made acoustic insulation measurement device according to ASTM E-336 (available in University of Technology, Materials Engineering Department), as shown in Fig. 4. It consists of four parts: wave generator device (UNIT 092812), device to amplify the wave (TNG, type: AV 298), loud speaker and wave receiving device (range 30dB -130dB). The test starts when the wave is generated by the wave generator device and then amplified. The wave then transferred to a loud speaker attached with a wooden box. The specimen was placed in the middle of this box, then the box was closed and the ranges of frequency are 20 frequencies were applied. For every frequency, the wave was taken from the receiving wave device. This test must be done in a very static medium and without any movement in the whole place, because this may lead to an imbalance of the obtained results. The sample used in this test has dimensions (240 ×240×10 mm^3). It is possible to determine the equivalent sound absorption of the samples by the Eq. (5) [9].

$$A = \frac{0.921 \times V \times d}{c} \qquad (5)$$

where:

A: The equivalent absorption of absorbing material.

V : The room volume (m^3).

c : The speed of sound (m/s).

d : The decay rate (dB/s).

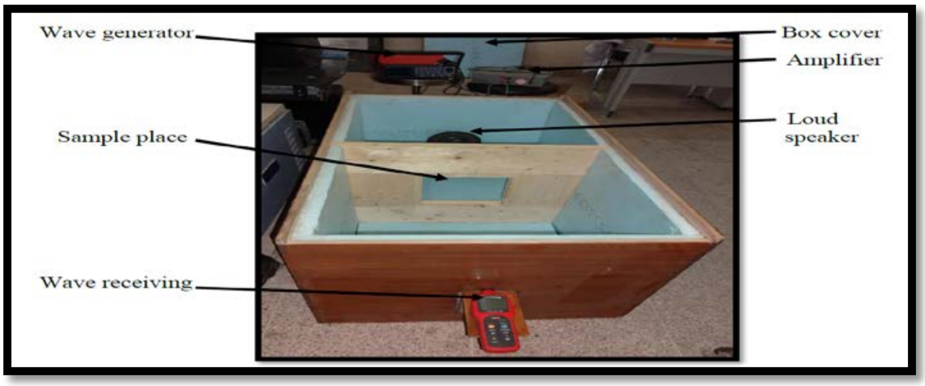

Fig. 4: Sound insulation device.

Results and discussion

1. Impact test

Fig. 5 illustrates the values of Charpy impact strength as a function of material type. It can be noticed that the value of impact strength for pure material increases after reinforcement with (Jute, Palm fronds, Reed and

Glass) fibers. The composite reinforced with Jute fibers showed the highest value of impact strength compared to other materials. The ratio of increment in the impact strength of jute composite compared with pure material is nearly equal to 95%. This means that Jute composite sample absorbs higher amount of impact energy before fracture. This is due to the nature of Jute fibers which is recognized in its ability to deform in plastic deformation and then the composite breaks in ductile fracture mode. This behavior can be obviously noted through the morphology of fracture surface which exhibits the characteristics of ductile fracture such as the dark and rough fracture surface. Fig.6 shows scanning electron microscope micrographs of the impact surface fracture of all composites, this images showed the voids in Reed and Fronds Palme fiber composite, this voids were represented weak regions that indicated to decrease the value of I.S for Reed and Fronds Palm Fibers composites.

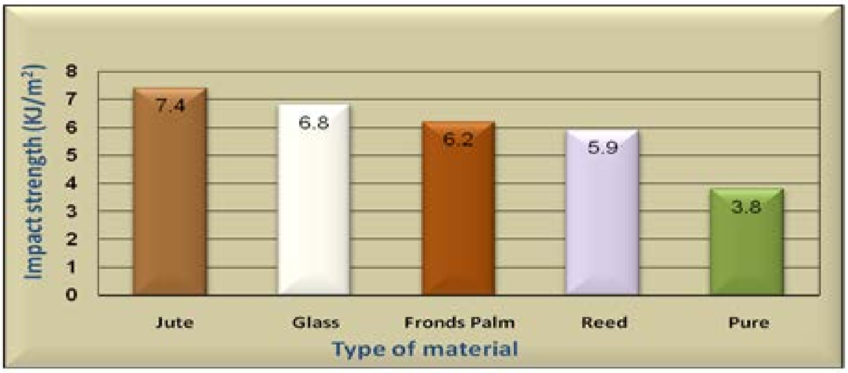

Fig. 5: The values of impact strength for the pure and composite materials.

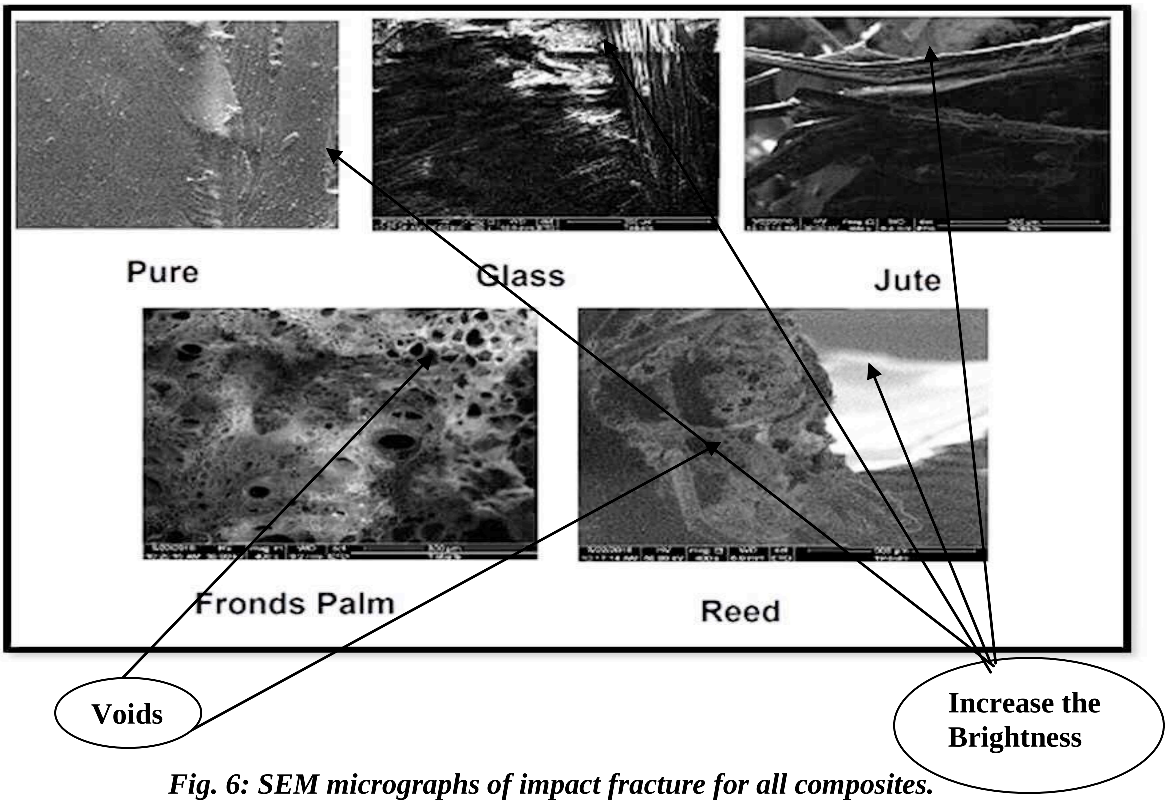

Fig. 6: SEM micrographs of impact fracture for all composites.

2. Flexural strength

Fig. 7 shows that the flexural strength of unsaturated polyester reinforced with Jute fibers is higher than that of Glass fibers and other natural fibers composites. The ratio of increment of the flexural strength for Jute composite compared with that of pure material is nearly equal to 144%. This result means that the value of flexural strength is depending on the adhesion between fibers and matrix as well as the adhesion between the laminates of fibers. These two factors would lead to distribute the applied load on more cross-sectional area of the composite. Also, the difference in the mechanical behavior between artificial and natural fibers composite is due to the difference in the mode load transfer at the fiber-matrix interface and consequently in the interfacial bond strength.

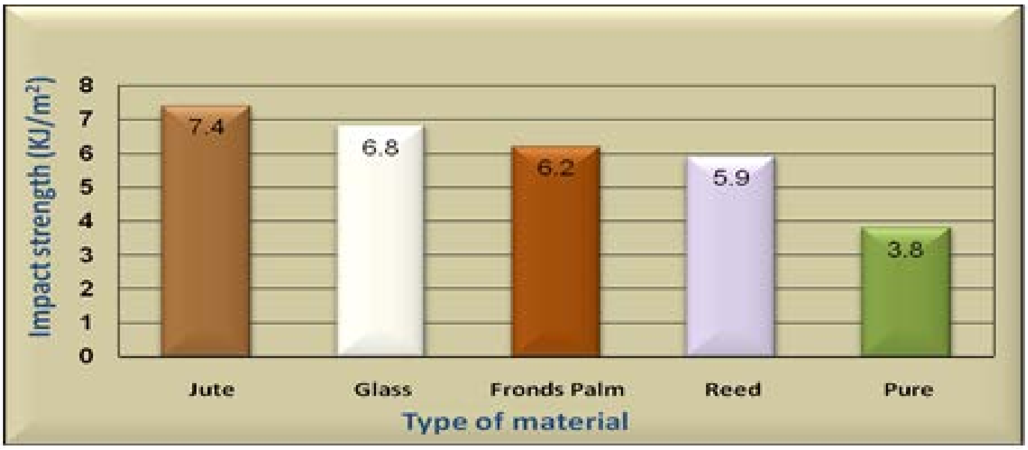

Fig.7: Comparison between the (F.S) for natural fibers with Glass fibers composites.

3. Thermal insulation

From the thermal conductivity test, the coefficient of thermal conductivity can be measured; it is measurement of the ability of material to allow the flow of heat from hot surface to the cold surface of it [10]. Fig. 8 shows the value of thermal conductivity for unsaturated polyester reinforced with Jute fibers which is less than that of glass and other natural fibers. This means that Jute composite exhibits good thermal insulation properties compared to other composites. There are several reasons behind this behavior; one of them the interface adhesion between Jute and matrix is very strong, the second reason is the ability of Jute fibers to absorb the matrix material is very high compared with other fibers because the nature of structure for Jute fibers is similar to weave material as cloth [11]. The experimental results of thermal conductivity coefficient of Fronds Palm composite is nearly to the study for R.Ch. Mohapatra which obtained that the coefficient of thermal conductivity of UP reinforced with Palm fibers is (0.4 W/m.°C) [12].

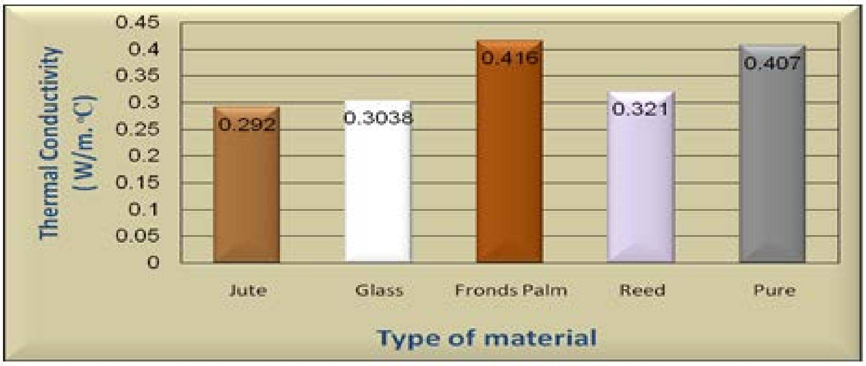

Fig.8: Comparison between the thermal conductivity for natural fibers with Glass fibers composites.

4. Acoustic insulation

The main parameters in the determination of the acoustic insulation properties are sound level and equivalent sound absorption. Figs.9 and 10 show the experimental results obtained for pure material, and after reinforced it with natural fibers and glass fibers. The results exhibit that the Jute composite has good acoustic insulation compared with Glass composite. Fig. 11 shows the comparison between the sound level intensity for natural fibers composites with Glass fibers composite. From Fig. 9 and 10, all natural fibers composites have higher acoustic insulation properties compared with artificial composites (Glass Composite), the reason is agreement with Vilay et. al. [13], "all natural cellulose are multi cellular, where a bundle of individual cells bound by natural polymers, such as lignin and pectin and have a hollow cavity called lumen exists in unit cell of the natural fiber". The presence of hollow lumen decreases the bulk density of the fiber and acts as acoustic and thermal insulators. In preview study S.A. Kadhim [6], the sound level intensity of (UP) reinforced with sawdust at 4000 Hz was (96 dB) while in the present study sound level was (92.2 dB) for Jute fibers reinforced composite.

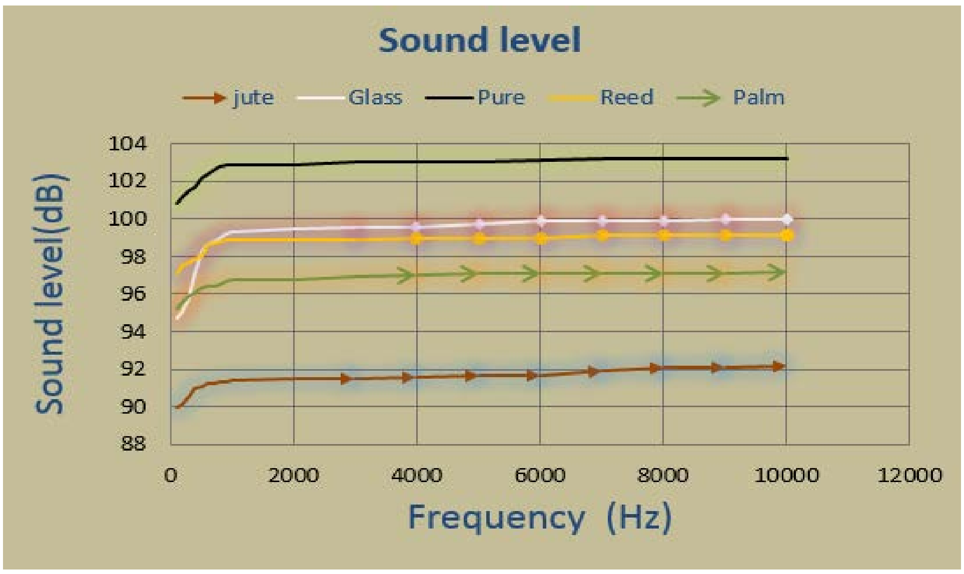

Fig. 9: Sound level-frequency relation for natural fibers composites with Glass fibers composite.

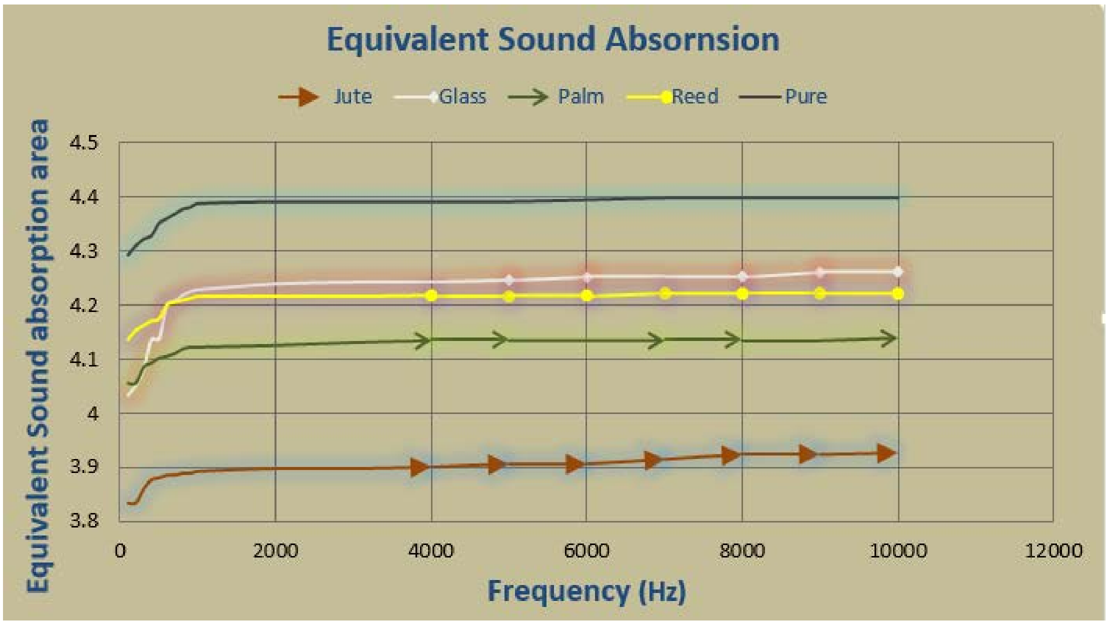

Fig.10: Equivalent sound absorption -frequency for natural fibers composites with glass fibers composite.

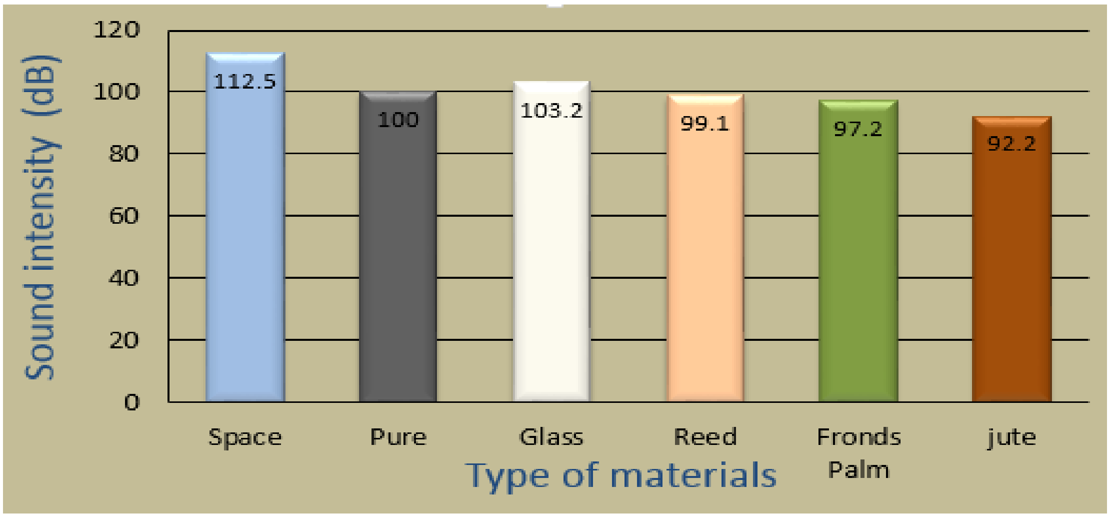

Fig.11: Comparison between the sound level intensity for natural fibers with Glass fibers composites.

Conclusions

In general, the results illustrate that the natural fibers (Jute, Fronds Palm and Reed) can be used as replacement for Glass fibers in acoustic insulation, thermal conductivity and some mechanical properties, because these fibers showed good results, it is eco-friendly materials, easy to handling by hand, and cheaper compared to glass fibers. Also, it can be concluded the following:

1. Jute fibers composite records higher values in (impact, flexural strength and acoustic insulation) while in thermal conductivity, it is less than other fibers so that it has a good thermal insulation,
2. Fronds Palm fibers composite showed impact strength (6.2 kJ/m^2) and flexural strength (97.1 MPa) which are higher than that of Reed fibers composite and pure material but less than that of Glass and Jute fibers. In thermal conductivity, it has a higher thermal conductivity (0.416 $W/m.^oC$) from other fibers while in acoustic insulation, it gives acoustic insulation

higher than that of (Glass, Reed and Pure) but less than that of Jute fibers.

3. Reed Fibers composite showed impact strength (5.9 kJ/m^2) and flexural strength (87.72 MPa) which are higher than that of pure material but less than other fibers. In thermal conductivity, it has a higher thermal conductivity (0.321W/m.^{o}C) compared to Jute and Glass but less than that of pure and Fronds Palm fibers which means that Reed fibers has high thermal insulation compared with Fronds Palm fiber and pure resin while in acoustic insulation, it is higher than (Glass, and Pure) but less than Jute and Fronds Palm fibers.

4. The ideal value of each test are:

Test	Materials	Value	Unit
Impact strength	J.C	7.4	kJ/m^2
Flexural strength	J.C	114.83	MPa
Thermal insulation	J.C	0.292	W/m°C
Acoustic insulation	J.C	92.2	dB

Finally, unsaturated polyester reinforced with Jute fiber showed the optimal properties compared with (Glass, Fronds palm and Reed) fibers composite and it is appropriate for application that needs to high mechanical properties, acoustic and thermal insulations.

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