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INVESTIGATION ON DIELECTRIC AND SOUND ABSORPTION PROPERTIES OF BANANA FIBERS REINFORCED EPOXY COMPOSITES

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Abstract

This research work focused on the development of banana fiber reinforced epoxy resin composites for dielectric and sound absorption applications. The dielectric and sound absorption properties of the composites were studied with respect to the fiber loading and treatment. The fibers were treated using 5wt % of sodium hydroxide at room temperature. The properties of the composites were measured using HP Impedance Analyzer E4980A and two-microphone transfer function impedance tube method according to the American Society for Testing Materials (ASTM D150-11 and ASTM E1050-12) standards. In general, the composites displayed higher dielectric constant and sound absorption coefficients at the higher fiber loading. In extend, the treated fibers reinforced composites showed higher sound absorption coefficients, but lower dielectric constant values.

Keywords: Banana fiber; sound absorption coefficients; dielectric constant; composites

Abstrak

Hasil kerja penyelidikan ini memberi tumpuan kepada pembangunan komposit daripada resin epoksi yang diperkukuhkan dengan serat pisang untuk aplikasi penyerapan bunyi dan dielektrik. Sifat-sifat komposit dari segi penyerapan bunyi dan dielektrik akan dikaji dari segi kepadatan dan rawatan serat tersebut. Serat akan dirawat dengan menggunakan 5wt% natrium hidroksida yang akan dikekalkan dalam suhu bilik. Sifat-sifat komposit akan diukur dengan menggunakan HP Impedance Analyzer E4980 A dan kaedah dua mikrofon pemindahan fungsi galangan tiub berdasarkan standard Persatuan Amerika untuk Ujian Bahan (ASTM D150-11 dan ASTM E1050-12). Secara umum, hasil ujikaji menunjukkan komposit dielektrik mempunyai pemalaran yang tinggi dan penyerapan bunyi yang tinggi untuk kepadatan serat yang tinggi. Secara lanjutan, serat yang dirawat untuk memperkukuhkan komposit menunjukkan penyerapan bunyi yang tinggi, namun mempunyai pemalaran dielektrik yang rendah.

Kata kunci: Serat pisang; pekali penyerapan bunyi; pemalar dielektrik; komposit

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1.0 INTRODUCTION

Natural fibers reinforced polymer matrix composites have been gaining importance in the automotive, transport, packaging, furniture, and building and construction industries. They have the potential to replace synthetic fibers that exist in above mentioned industries. Natural fibers have specific stiffness which is similar to synthetic fibers, and this makes them attractive as renewable alternative to synthetic fibers. The various advantages of natural fibers over synthetic fibers are recyclability, low cost, renewability, low density, comparable specific tensile properties, reduced energy consumption, nonabrasive to the equipment's, non-irritating to the skin, less health risk, and biodegradability [1]. With the improvement in the properties of fiber reinforced polymers, these composites are widely accepted for use in structural and non-structural applications. The banana plant is abundantly grown and these are considered waste after the fruits are ripened. Hence, the banana fiber obtained from the plants can be explored as a potential reinforcement.

Banana fiber is considered as an active reinforcing constituent due to its good compatibility and bonding with polymer matrix. It is considered as a lignocellulosic material, comparatively inexpensive and abundantly available, when assessed in terms of its fiber/polymer matrix adhesion [2]. Epoxy matrix composites are composites made from resins which cross-linking during curing. Cross-linking is induced either by addition of curing agents or by heating. As a result of cross-linking, epoxies normally have better strength and stiffness than thermoplastic matrix [3]. Epoxy resin has been used extensively as a matrix resin in research into natural fiber composites, since it has been found to bond well to natural fibers because of its affinity for the hydroxyl groups attached to cellulose [4]. Ramesh et al. [5] conducted flexural, tensile, and impact properties of banana fiber reinforced epoxy composites and found that the maximum tensile, flexural, and impact strength of 112.58 MPa, 76.53 MPa, and 9.48 Joules respectively for 50 % banana fiber and 50 % epoxy composites. Maleque et al. [6] investigated the mechanical properties of banana fiber reinforced epoxy composite. They found that the tensile strength of the pseudo-stem banana fiber reinforced epoxy composite associated with neat epoxy is increased by 90 %. Also they reported that, the impact strength of the composites improved by approximately 40 % compared to the impact strength of neat epoxy. The impact strength value is higher which indicated to a higher toughness value of the material. Sumaila et al. [7] investigated the influence of fiber length on the physical and mechanical properties of non-woven random oriented short banana fiber epoxy composite. They found that the tensile properties and percentage elongation of the composite attained a maximum performance in composite fabricated with 15 mm fiber length. They have also reported that the impact energy is decreased whereas the compressive strength increases with increasing fiber length, also the mean flexural properties of the composite increased with increasing in fiber length up to 25 mm.

There are many reports available on the mechanical properties of banana fiber reinforced epoxy composites, but, the sound absorption and dielectric properties of the banana fiber reinforced epoxy composites is rarely being reported. To this end, the present work has undertaken with the objectives to investigate the sound absorption coefficients and dielectric properties of the composites. The materials tendency to conduct electricity is generally expressed by the term of surface resistivity (i.e. how they demonstrate resistance to transferring electrical charges). There is an emerging interest in the development and applications of electrically conductive polymeric composites, particularly on the natural fiber reinforced conductive polymer composites in different aspects of industrial applications [8]. These composites were effective insulation and desirable high levels of mechanical strength that enables it to be an excellent mechanical support for field carrying conductors. Several researchers found the efficiency and appropriateness of the natural fibers as fillers for conductive polymers. Numerous studies have investigated the dielectric properties of composites made from natural fibers with various polymers. Dielectric properties of the conductive composites depend upon various factors like the composition, physical texture, chemical structure and the morphology of the composites.

Therefore, investigations regarding the dielectric properties such as dielectric constant, dissipation factor, loss factor, and conductivity are required for the successful industrial applications. With the current development of technology, the noise pollution becomes a major problem. Thus, there are demanding and need to find alternative materials that capable to reduce the noise level at various ranges of frequencies. Environmental concerns have resulted in a renewed interest in sustainable composites focusing on bio-based fibers. Thus, this cause a lot of researches on composite materials and natural fibers were done on acoustical panels. The common acoustic panels are made from synthetic fibers that are hazardous to the environment and human health and quite expensive for small needs. Although, dielectric and sound absorption coefficients of some natural fibers have been investigated, the banana fiber properties with respect to dielectric and sound absorption are rarely studied. Hence, this research focused to investigate the potential of using banana as raw material for epoxy resin for dielectric and sound absorption applications.

2.0 METHODOLOGY

2.1 Materials

The materials used in this work are banana fibers, epoxy resin, sodium hydroxide, and acetone thinner. Banana fibers are obtained from local sources in Kuching, Sarawak, Malaysia. Banana fiber comes from the family name of *Musaceae*, a type of bast fiber extracted from the banana tree. The structural compositions of banana fibers were cellulose 43.46wt %, Hemicellulose 38.54wt %, and lignin 9wt %. The amount of metal elements present as irons in banana fibers were Al3+ 0.14, Ca+ 5.72, Mg+ 1.77, Na+ 0.28, and Si4+ 1.41 [9]. Table 1 shows the physical and mechanical properties of banana fibers.

Pre-mixed types of epoxy resin with product code 'BBT 7892 A' and epoxy hardener with product code 'BBT 7892 B' were supplied by Borneo Indah (Malaysia)

Sdn. Bhd. This product contained bisphenol-A for part 'BBT 7892 A' resin and polyoxypropylene diamine and diethylenetriamine for part 'BBT 7892 B' hardener. These types of epoxy resin had a low reactivity, slow curing and yellowish in color. Fibers were immersed in a 5wt % sodium hydroxide solution at room temperature for 24 hours.

The sodium hydroxide solutions were obtained by dissolving the pellet forms of caustic soda with distilled water. The immersing of fiber with sodium hydroxide solution enabled the removal of impurities and increased the surface roughness of the fiber. The immersed banana fibers in the sodium hydroxide solution were later cleaned with distilled water until neutral pH is attained and dried in an oven at 60 °C for 48 hours in order to remove free water. The drying oven with model name 'ECOCELL EC55' and brand 'MMM Group' equipped by Fisher Scientific, UK was used in the process. The treated fibers were cut to the required dimensions and stored in an airtight container.

2.2 Fabrication of Composites

The composite fabrication process adopted here is cold compression. Epoxy was mixed with the hardener at a ratio of 4:1 resin to hardener (4 amount of part 'A' and 1 amount of part 'B'). Both untreated and treated fibers, acts as fillers being mixed together with epoxy achieved 5wt %, 10wt %, 15wt % and 20wt % fiber loading. The mold used for sound absorption test has circular cavities of 25 mm in diameter and 5 mm thickness that complied with ASTM E1050 [10] standards. Meanwhile, dielectric mold with a diameter of 50 mm and thickness of 5 mm were also fabricated according to ASTM D150-11 [11] standards. The molds were waxed before filled with the mixture of composite ingredients. The releasing wax contained carnauba that used to prevent the sample stick and stuck in the mold when removing the samples out from the mold. Mixture of epoxy and fibers were then poured into the mold and compressed by using hydraulic hot/cold press machine with model code 'LS-22071' equipped by Lotus Scientific (Malaysia) Sdn. Bhd. under a pressure of 10 MPa. The molds were then left in the press machine for 24 hours under standard room temperature 24±1 °C for curing purposes.

Table 1 Physical and mechanical properties of banana fibers [9]

Width (or) diameter (µm)	Density (kg/m^3)	Cell L/D ratio	Microfibrillar angle (°)	Initial modulus (GPa)	Ultimate Tensile Strength (MPa)	Elongation (%)
80-250	1350	150	10±1	7.7-20.0	54-754	10.35

2.3 Testing

The dielectric properties of the composites were measured with an HP Impedance Analyzer E4980A. The dielectric constant measurement program assists in carrying out the measurements using the Agilent E4980A precision LCR meter and the 16451B dielectric test fixture. The LCR meter is capable of measuring up to a frequency of 2 MHz. The specimens were analyzed using a contacting electrode method, which uses a rigid metal electrode. Measurements were done at varying frequencies ranging from 1 kHz to 1 MHz in accordance with ASTM D150-11 [11] standard. The sound absorption coefficients of the natural fiber composites were tested in the acoustic frequency range of 500 Hz to 6000 Hz for acoustical testing. The sound absorption coefficients were obtained from two-microphone transfer function impedance tube test rig, according to ASTM E1050-12 [10] standards.

3.0 RESULTS AND DISCUSSION

3.1 Dielectric Constant

Figure 1(a) and 1(b) shows the variation of dielectric constant with fiber loading as a function of the logarithm of frequency at room temperature for untreated and treated banana fiber reinforced epoxy resin composites. In both cases, these figures clearly show that the dielectric constant increased with increasing fiber content at all frequencies. Neat epoxy resin shows the least dielectric constant values at all frequencies. It is because of the non-polar molecules of epoxy having only an atomic and electronic polarization that contributed to the polarizability. Banana fibers are having polar in nature and their introduction into the non-polar epoxy resin leads to an increase in the number of polar groups inside the composite and this leads to polarization orientation or dipole orientation.

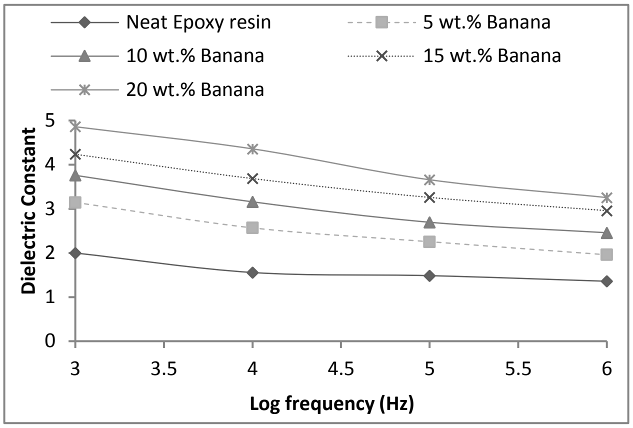


Figure 1(a) Effect of untreated fiber content on the dielectric constant of banana reinforced epoxy composites as a function of logarithm of frequency at room temperature

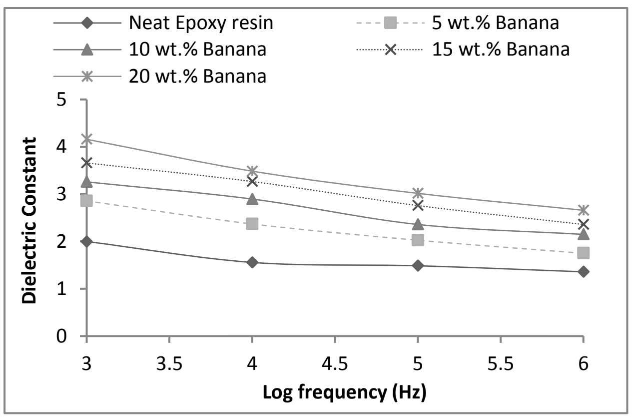


Figure 1(b) Effect of treated fiber content on the dielectric constant of banana fiber reinforced epoxy composites as a function of logarithm of frequency at room temperature

The banana fiber reinforced epoxy composites are heterogeneous in nature and hence interfacial polarization also contributes to an increase in the dielectric constant. At low frequencies complete orientation of the dipoles are possibly leading to the high dielectric constant in the composite. Though at high frequencies the molecular vibrations are high and hence complete orientation of dipoles does not take place and therefore the dielectric constant decreases as frequency increases in all the composites. It was observed that, the sodium hydroxide treated fiber composites show lower dielectric constant than the untreated fiber composites for all the frequencies. This was due to the decrease in orientation polarization as a result of the increased hydrophobicity of the treated fibers. Sodium hydroxide treated fibers also reduces the moisture absorption tendency of the fibers due to the reduction in the probability for the interaction between polar –OH groups of banana fibers and water molecules.

3.1 Dissipation and Loss Factor

The dissipation factor of the untreated banana fiber reinforced epoxy composites are depicted in Figure 2. It has been observed that the dissipation factor increased with increase in fiber content and decreased with an increase in frequency. This is due to the increase of the banana content which increases the polar groups that are present, which leads to an increase in orientation polarization. And also observed that at high frequencies the orientation polarization is difficult, this is the causes for significant decrease in the dissipation factor at high frequencies. The dissipation factor is lowest for neat epoxy and highest for 20wt % of banana fiber. The measurement of dissipation factor of an insulating material is important since the loss tangent is a measure of the electrical energy, which is converted to heat in an insulator [12].

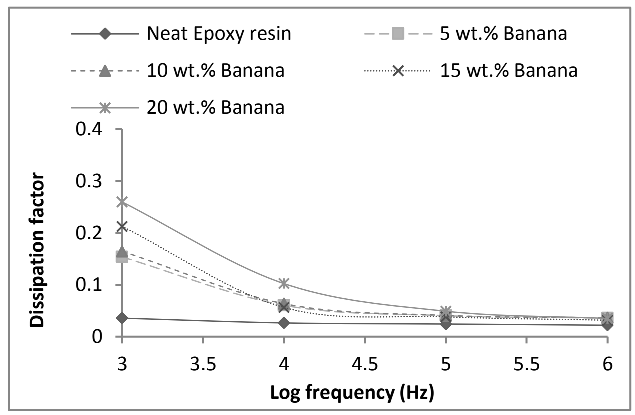


Figure 2 Effect of untreated fiber content on the dissipation factor of banana reinforced epoxy composites as a function of logarithm of frequency at room temperature

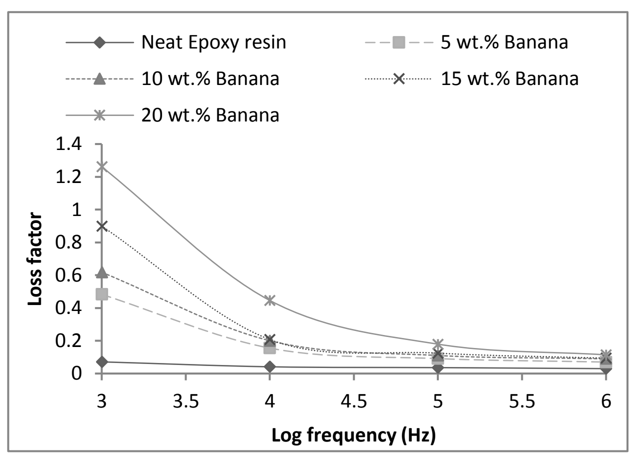


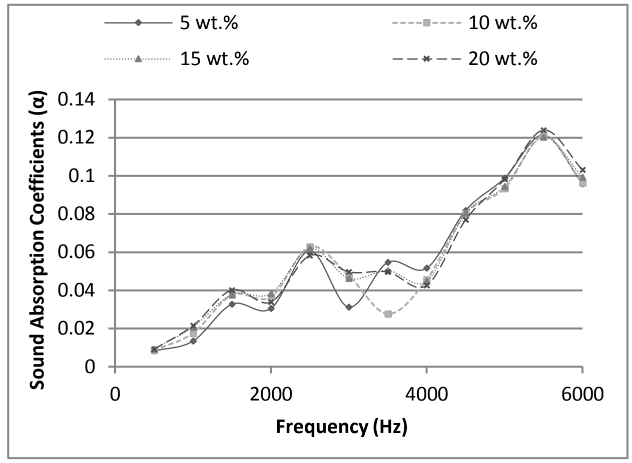
Figure 3 Effect of untreated fiber content on the loss factor of banana reinforced epoxy composites as a function of logarithm of frequency at room temperature

The variation of loss factor for the composites as a function of frequency is depicted in Figure 3. It can be observed that in the lower frequency region, the loss factor is high and is highest for the composites having a banana content of 20wt % at a given frequency. It shows that in the lower frequency range the loss factor depends upon the fiber content due to polarization of the fibers, which is absent at higher frequencies. In energy industries the loss factor is used to indicate the losses in transmission and distribution, because loss factor is an expression of the average power factor over a given period of time [12].

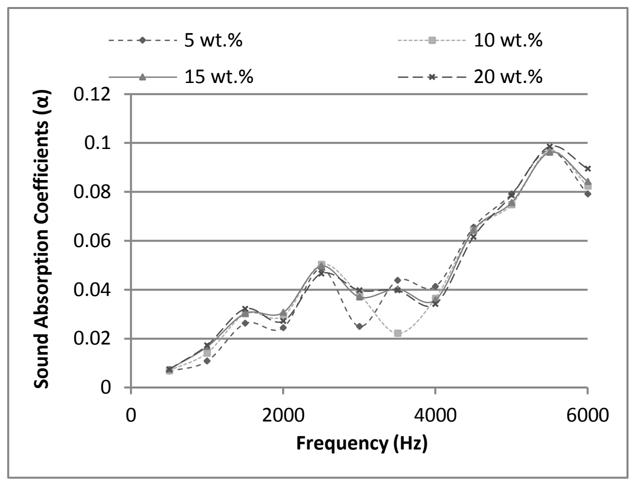
3.2 Sound Absorption Coefficients

The sound absorption coefficients of the treated and untreated banana fiber reinforced epoxy resin composites are shown in Figure 4(a) and 4(b). All the composites show higher sound absorption at high frequencies. From the figures, it was observed that, when the fiber content increases the sound absorption coefficients of the composites also increased. The highest sound absorption was obtained for 20wt % and the lowest for 5wt % banana fiber composites. For the short banana fibers, due to its random distribution in the epoxy matrix, there is a considerable portion of porous structure, which can absorb sound waves [13]. Peng et al. [14] investigated the sound absorption coefficient of the wood fiber and polyester composites. They found that composites had a higher sound absorption coefficient at high frequencies. A similar study was conducted by Yang et al. [15] utilized rice straw with commercial binder, they found that the sound absorption coefficient of 0.5 between the frequency of 1000 Hz to 8000 Hz. By compared with Yang et al. [15], the sound absorption coefficient of the rice straw composite was found to be higher than the banana composite. It was due to the thickness and different polymer used in the rice straw composite, which is much thicker and porous than the banana composite.

However, it is predicted if the banana composites having a same thickness and same polymer as the rice straw composite, if would have similar or higher sound absorptions than the rice straw composite. It was also observed that, the composites with treated fibers have a higher sound absorption coefficient compared with the untreated fibers. In the untreated fibers, a dense layer of hemicellulose, lignin, pectin, and other low molecular weight materials can form a dense layer on the surface of banana fibers [13], so the reflection is higher and lower the sound absorption coefficient. By sodium hydroxide treatment, the lower molecular weight materials were removed, so the reflection is lower and higher the sound absorption. The sound absorption coefficients of the composites increased as the frequency increased. However, they decreased at certain frequencies and started increasing again. This fluctuation (decrease and increase) was due to the specific characteristic (i.e. tortuosity, porosity and density) of banana fibers. Whereas, the tortuosity in the fiber will re-directed the sound, porosity will cause inter-reflected sound, and different density at section of the fiber will create different sound energy absorption. Figure 5 shows the illustration of tortuosity.



(a) Treated banana fiber/epoxy resin composites



(b) Untreated banana fiber/epoxy resin composites

Figure 4 The sound absorption coefficients

The banana fibers were more compact within the epoxy matrix at high fiber loading. The banana fiber was packed closer to each other within the matrix. This compact structure caused a reduction in the size and the volume of the air void fractions within the composites, which indirectly produced narrower passages for sound wave. This also cause increase in the tortuosity of sound propagation, which will allow the sound to travel in a longer distance than the usual distance. Jiang et al. [16] showed similar results in their study of the acoustic properties of seven-hole hollow polyester fibers (SHPF). At increasing fiber loading, the sound absorption coefficient of the SHPF composites shows an increasing trend. Furthermore, Markiewicz et al. [17] also reported that the sound absorption coefficients of PP-long hemp fiber composites, PP-crumble hemp plant composites, PP-rapeseed straw kaszub composites, and PP-long flax fiber composites increased significantly with the change in the fiber loading, especially in the medium and high frequencies of sound.

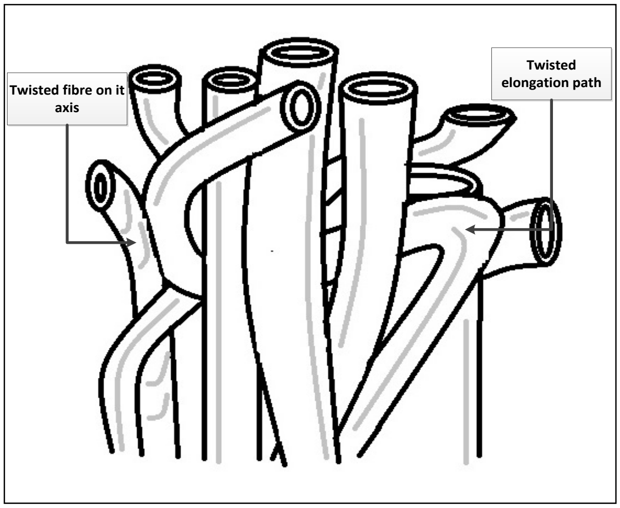


Figure 5 Illustration of tortuosity in fiber

Moreover, porosity is another factor that may influence the sound absorption. Beside the size of the pores, the number and types of pores also influenced the sound absorption of the materials [18]. Figure 6 shows types of pores for hollow lumen structure. Meanwhile, some pores tend to propagate the sound and dampened it. At fiber loading of 20wt %, it is found that the composites have the sound absorption coefficient lowered than the 15wt %. The reason behind this may be due to the difference of the microstructures between the two composites. For the composite at 20wt % fiber loading, the hollow lumen structure is collapsed, thus this shorted the sound to travel inside the natural fiber epoxy composites. This characteristic is not observed for the 15wt % fiber loaded composite.

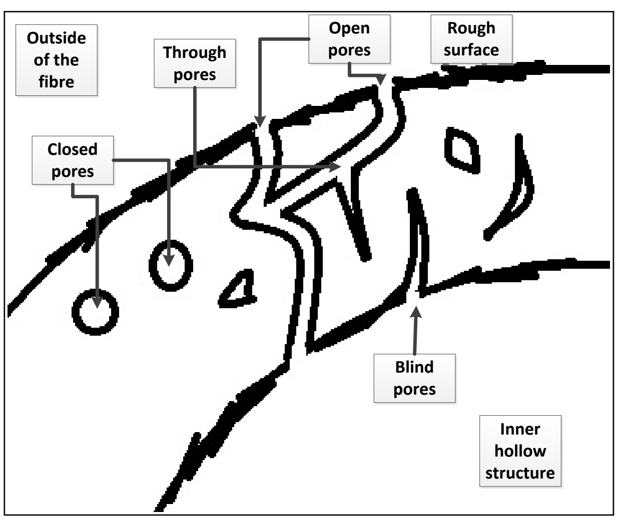


Figure 6 Illustration of type of pores in hollow fibre of tortuosity in fiber

The chemical treatment using sodium hydroxide and heat treatment cause the fiber to shrink, and hence affects the structure of banana fiber. Changes in the structure of banana fiber caused the elimination of liquid-structure (i.e. moisture) inside the banana fiber. Thus, this caused the epoxy to absorb into the fiber easily. The absorption of epoxy caused the closing in the porous structure of the fiber and hence reduces the porosity. Furthermore, according to Fouladi et al. [19], the mix between the matrix and the fiber during fabrication causes the matrix and the fiber act as one part of the materials itself. This indirectly will create a less porous structure with lower tortuosity for sound propagation.

4.0 CONCLUSIONS

Banana fibers reinforced epoxy resin composites were developed as the next generation materials to replace their synthetic counterparts in sound absorption and dielectric applications. The effect of fiber content and treatment on sound absorption and dielectric properties of the composites was investigated. The composites made of the higher fiber content were having the higher sound absorption coefficients as well as higher dielectric constant values. In all the cases, when frequency increased, the sound absorption coefficients also increased. The composites investigated in this study have interesting sound absorption coefficients (α=0.124) and the dielectric constant (ε=4.8) values. Sound absorption coefficients of the cold compressed composites are generally lower. Because of the resins would occupy some effective volume of airflow, as well as cavities between natural fibers and inside lumens. Banana fiber was an effective reinforcement of the polymer matrix. This has created a range of technological applications beyond its traditional usages. The result shows that banana fiber can be a better alternative than other natural fiber in the application areas of sound absorption and dielectric properties.

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