Processing of Orange Peel Biomass waste of Juice Industries and Valorization to Smart Acoustic Material

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Research Article

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Processing of orange peel biomass waste of juice industries and valorization to smart acoustic material

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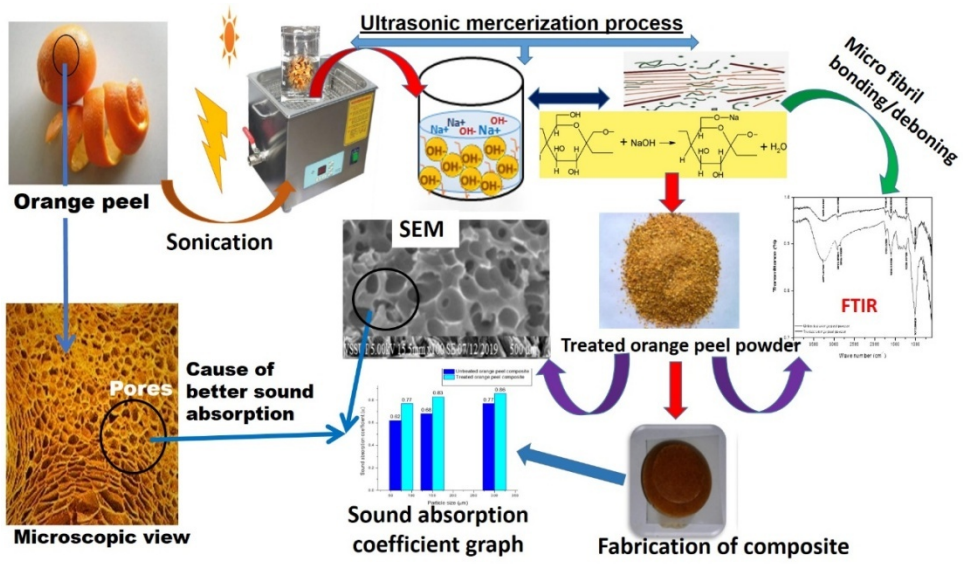
Abstract:
Non-destructive technique like ultrasonication has played crucial role in fabrication of effective graded acoustic material using carbon rich organic waste material. The peculiar structural configuration inside the fibrous material like orange peel have attract the researcher to create special interest in designing of some building acoustic material as well as many technological products. The noise reduction property of orange peel fibres of different particle size has been improved considerably after ultrasonically mercerization of NaOH.High penetrating and dispersive property of ultrasonic wave to assemble and regrouping among the fibrous material are quite remarkable for enhancing noise attenuation inside the composite. Scanning Electron Microscopy (SEM), Energy Dispersive Spectra(EDS), Fourier Transform Infra-Red(FTIR) and X-Ray Diffraction(XRD) analysis of both untreated and treated orange peel fibre of different particle size indicate the deformation in cellulose as well as anti cellulose with the aid of ultrasonicationpermits the composites to be a suitable acoustic material. The result confirm that ultrasonic treated composite has potential to absorb 88.6% of sound which makes it a class- B noiseabsorber with peripheral mechanism within the composite.

Graphical abstract



Statement of Novelty: Influence of particle size plays the crucial role in designing and fabrication of effective graded noise reduction material. Application of high frequency ultrasonic beam through alkali solution enhances the active sites with ideal noise absorption efficiency.

Key words: Acoustics, mercerization, particle size, sound absorption, ultrasonic technique

Introduction:

Recent data published in the eve of International Noise Awareness day held in the month of April 2021 highlights the fact on noise pollution and development and designing of acoustic material which considerably increases the

enthusiastic approach for the researcher attraction towards the design and fabrication of green acoustic material with consideration of environmental effect. In recent years, the persistence of diverse sounds in the environment and human living surrounds has become a tough problem[1]. Despite the fact that various methods and gadgets have been created to lower noise levels in the house, more effective and promising materials are still required. The use of ultrasonic mercerization process as surface treatment improves sound absorption while also providing a good reinforcement by linking orange peel fibres with a polymeric matrix.

To handle the current noise pollution problem, the replacement of conventional material with bio material can be considered. Despite the fact that crop cultivation for bio material uses very little land, the use of lignocellulosic waste materials for the manufacture of green biomaterials is becoming increasingly more popular recently.Urban noise is considered as main source of anthropogenous ecological degradation of universal highly urbanized communities by World Health Organization. It is undeniable that the expansion of ubiquitous industries, technology, and science may significantly improve living quality. However, this approach frequently adds to a variety of issues, the most of which are connected to human health and environmental conditions. Noise pollution also has an impact on society, notably on the lives of city dwellers. Two concerns that must be addressed in modern civilizations are noise pollution and waste management. These problems are greatly reduced by the use of recently developed alternative noise-absorbing materials. Sound absorption constitutes one of the major requirements of anthropogenic world today. As a result, composite materials those are inexpensive, simple to manufacture, compact, and lightweight, as well as those that can absorb sound waves across a larger frequency range, are extensively desired[2]. Today's sound-absorbing materials mostly consist of manufactured items like foam, recycled rubber, glass wool, and synthetic fibre, which may be harmful to human health, disruptive at work, and ecologically damaging. The fibre sound-absorbing materials have been thoroughly researched. Biot studies give a method for the proliferation of elastic wave into solid medium drenched at higher and lower frequencies, where parameters such as pore geometry, fluid, and medium with equivalent densities must be taken into account in case of porous material . As a result, using natural materials instead would be preferable. The processing of synthetic fibres is also very detrimental to the environment as well due to the reason that they are made from high temperature industrial process such as hot extrusion, and the synthetic fibres are often derived from petrochemical sources producing a large amount of carbon footprints. Because of the disadvantages of synthetic fibres, focus is being drawn to the use of natural fibres as a primary material in the manufacture of sound absorber. In comparison to synthetic fibres, natural fibres are cheaper, abundance, renewable, etc. Natural fibres are also classified as renewable materials and could be essential to an alternative approach for the potential production of greener sound absorbers. The surface of fibrous materials are mainly porous, this is due to the voids present on the surface that helps to achieve porosity of the material and if the surface is highly porous, the incident sound wave perforate into the material and the air molecules present at the surface of the material and the pores of the material are forced to vibrate within the structure allowing internal sound reflections as a result of which heat is generated at the walls of interior pores due to the thermal and viscous loss and ultimately causing acoustic energy loss. At low frequency isothermal changes are illustrious as domain and at higher frequency adiabatic changes are domain aspect[3]. Bio fibres which are natural polymers can be made from wide range of fruits and vegetables, and they have some of the unique properties that distinguish them from conventional fibres. Orange peels are obtained by peeling off the orange fruit's outside covering. The peels can be processed for the manufacturing of polymer composites and for various home uses as reinforcements. Orange is a citrus fruit found mostly in Southeast Asia. The pH range is acidic from 2.9 to 4.0. Many researchers have carried out research on orange peel as a biodegradable ecofriendly reinforcement, water absorption capabilities of orange peel particles of different compositions[4]. Orange peel composites treated with a coupling agent had better strength because the matrix and reinforcement interface were more compatible[5-6]. According to the report by Food and Agricultural Organization (FAO), at about 40%-60%of oranges are produced for juice industries[7]. Left over orange residues after juice are mainly rich in polysaccharides like cellulose, hemicelluloses and pectin in membranes and peels. Despite of valuable contains, if orange peel is not treated correctly it may cause environmental effluence due to its high organic value, water and very low pH value. Orange peel wastes are mostly employed in the extraction of an oily material that is used in chemical preparations. There is very less technological practical applications of orange peel in spite of their large availability. Orange peel wastes are being used in composites

technology for acoustic purposes, in addition to their original use. The novelty behind this work is that in orange peel the unique peculiar structural configuration of its constituents has significant efficiency for blocking and dispersion of high intensity wave within it as shown in Fig.1. The structural arrangement of different chemical composition of orange peel indicates that a large number of porous structure formed due to bonding and de bonding of cellulose, hemicelluloses, pectin, lignin, etc. Ultrasonic mercerization using sonicator has been adopted for surface treatment of fibres with 1N NaOH solution regardless excessive use of chemicals which will lead to weaken the mechanical strength of the fibre. The high frequency ultrasonic wave helps in binding the atomic and sub atomic spaces of the surfactant with the fibre porous region by altering the thermodynamic property of the surfactant. Based on the aforementioned, the present work is carried to study the potential of mercerized orange peel bio composites for better acoustic performance[8]. Thus it is a challenging issue to enhance the noise reduction coefficient by potential use of orange peel waste material and its fabrication, characterization and application to high extent for synthesis of different class of acoustic material with ideal absorption coefficient of absorption of noise with variation of particle size attracts the researchers in development of smart acoustic material

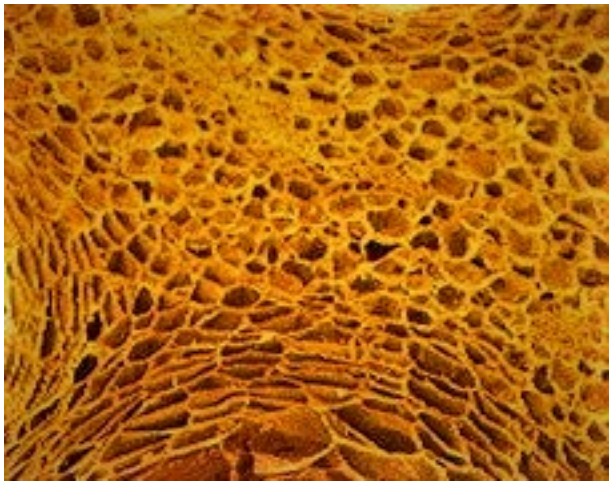


Fig. 1 Structure of orange peel under microscope

Materials and methodology

Pretreatment of orange peel waste for fabrication of composite

For preparation of orange peel composite, peel of well matured and ripened oranges were collected from local area and was dried under sunlight for 4-6 days. Aqueous solution of NaOH was prepared with impregnation of high frequency ultrasonic wave of frequency 125KHz. NaOH pallets were dissolved in 100ml water and placed inside ultrasonic bath for homogenous mixture of surfactant. After well dispersion for 1 hour, the solution was ready for treatment of orange peel. The dried peels were treated were soaked in aqueous NaOH solution for 10-15 minutes and then washed with distilled water to neutralize the pH. The treated peels were placed in oven for 2hours at 60°C for removal of the moisture. With the help of a grinder the dried orange peel were converted into small particles from which the desired size like 75µm, 150µm, and 300µm were separated using sieve method as shown in Fig. 2. Hand layup method was acclimated for fabrication of composite. For a well-mixed polymer matrix, blend of epoxy resin and hardener in a weight ratio if 10:1 was agitated for 30 minutes in a beaker. Orange peel fibre of different particle size 75µm, 150µm, 300µm were added to the polymer matrix in different beakers and stirred for 15 minutes for proper mixing. The mixture was pour into the mold of dimension 15x15cm. Silicon sheet was used to cover the upper and lower part of mold so as to maintain good finishing of the surface of the composite. Samples were pressed using c- clamps and left to dry for 24 hours. Samples of different particle size were prepared for physical characterization and acoustic testing as shown in Fig. 3.

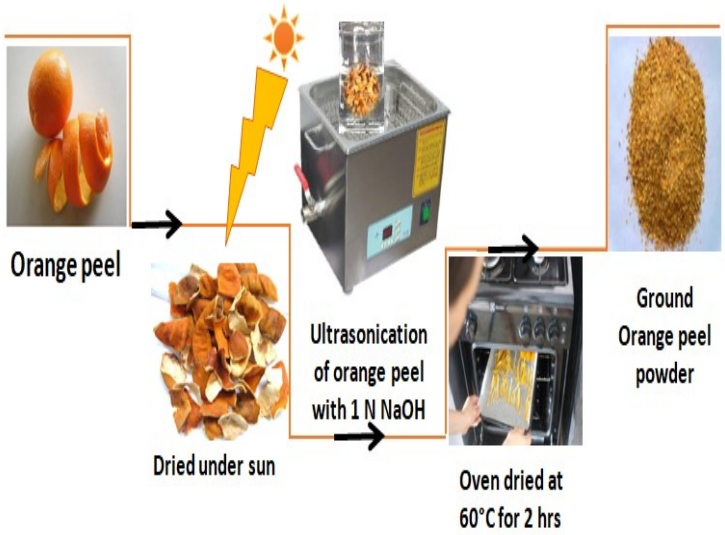


Fig. 2 Method of collection of orange peel powder

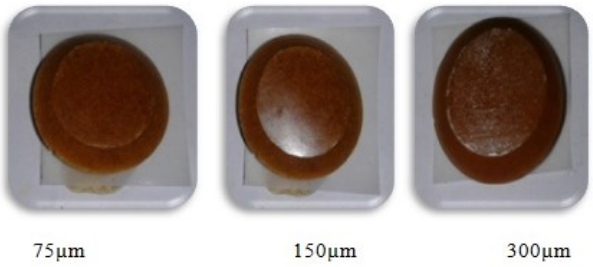


Fig. 3 Synthesized sample

Mechanism of ultrasonication in modifying the surface of orange peel

The process of ultrasonic irradiation has been adapted to mercerize orange peel in order to increase the stability of emulsion between orange peel and aqueous NaOH. Schematic diagram of entire process of ultrasonication as well as structural change in orange peel before and after mercerization has been shown in Fig. 4. A beaker containing small pieces of orange peel in NaOH solution was kept inside the steel chamber containing cold water which is placed inside bath sonicator operated at frequency of 125 kHz and 60W power. The chamber is connected to the ultrasonic generator which creates electrical signal to power the ultrasonic transducer. Transducer converts the high frequency electrical signal to ultrasonic wave by creating mechanical vibration using piezoelectric crystal. When this ultrasonic wave propagates inside the water chamber it gives rise to compression and rarefaction[9]. The compression cycle exerts a positive pressure on the beaker containing the mixture by pushing molecules together whereas rarefaction exerts a negative pressure by separating molecules from each other. Due to this negative pressure generation and growth of micro vacuum bubbles occurs. With increase in size of micro bubbles they acquire an unstable dimension consequently collapse violently and result in generation of shock wave creating cavitation. These bubbles act like miniature high speed brush heads which moves faster increasing collision frequency to assemblage of orange peel with the NaOH solution. The schematic of ultrasonication process shows, with increase in acoustic pressure and temperature of the medium, the de bonding of Na^{+} and OH^{-} occurs due to cavitation which assembles with OH group of orange peel and removes water in the form of water vapor making the orange peel hydrophobic. The mercerization of orange peel with NaOH during ultrasonication as per the following equation.

$$Orangepeel - OH^- + Na^+OH^- \xrightarrow{Mercerization} Orangepeel - O^- - Na^+ + H_2O\uparrow$$

The schematic showing mercerization explains the structure of orange peel before and after ultrasonication respectively. Before ultrasonication the presence of micro fibrils like lignin, cellulose, hemicelluloses in the orange peel confirms the dry and porous nature with smooth surface containing impurities and foreign materials. This makes the untreated orange peel to be an elastic body up to fracture. With mercerization, deformation in orange peel structure attributes to change in physical and chemical property[10]. Alignment of micro fibrils is damaged due to breakage of network structure of cellulose due to breaking of hydrogen bonding. Due to absence of hydrogen bonding the stiffness of the orange peel decreases as a result the pore size increases creating rough surface for easy absorption process.

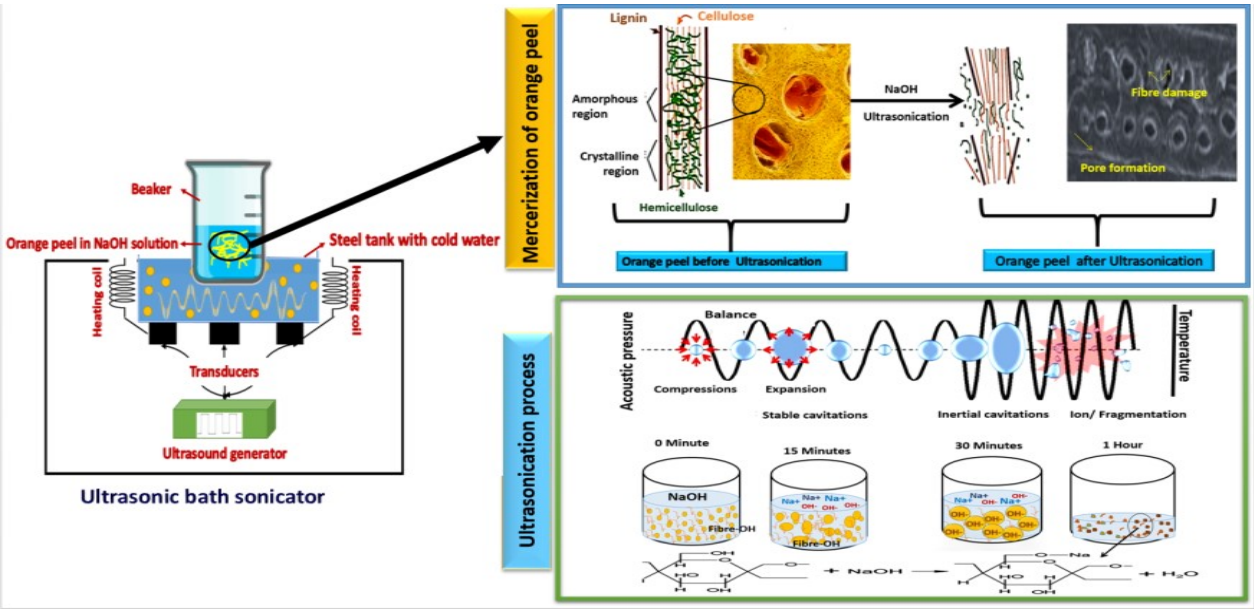


Fig. 4 Schematic of ultrasonicated mercerization of orange peel

Characterization of orange peel and composite

The morphological behavior change that occurs at various steps of Orange peel fibres processing were analyzed using scanning electron microscope (HITACHI SU 3500) at a voltage of 5kV. Required sample specimen were cut and made slicewhich was place over an Aluminum stump fixed with a double tape and sputter coated with gold. In order to make the sample conductive, current of 18mA and pressure of 1 torr was applied. The surface pictures at different magnifications were captured in various regions to provide a clear picture of the surface alteration. The composition of elements present in the composite was investigated using energy dispersive spectra (EDS). In addition, FTIR spectra of orange peel powder was obtained by Fourier Transform Infrared Spectroscopy (Bruker Alpha-II USA) for the wave number ranging from 4000-500 cm^{-1} in transmittance mode, which provides configuration of the distinct functional groups present on the untreated and treated orange peel. Powder X-ray diffraction (XRD) was carried out with BRUKER D8 ADVANCE for mineralogical analysis to reveal the elements present in the material. The diffractometer was well-found with CuK_α x-ray source of 1.54060 A° wavelength where Cu is considered as anode material. The diffractograms were collected from $2\theta=10^\circ$ to $2\theta=80^\circ$ at a fixed divergent slit

at 10°. The ray tube was set at 30mA and 40kV.PANalyticalX'PertHighscore software has been used to analyze the pattern of peaks as well as crystalline structure of the orange peel.

Experimental setup for acoustic measurement

Experimental setup comprising of impedance tube (HOLMARC-HO-ED-A-03) was used for the analysis of sound absorption by the composite. The system consists of an anodized aluminum tube of 50 mm diameter to retain a material sample whose acoustic properties are to be tested at one end and speaker at other end to generate sound at normal incidence, that is, 0°. A pair of microphones separated by a defined distance is connected to this tube using microphone holders. These microphones are connected by means of signal conditioners and a data gathering system to a digital signal analyzer. The speaker in the impedance tube is powered by a function generator. Test sample's acoustic properties were estimated using the transfer function technique, which separates the incident and reflected energy from observed transfer function before estimating the test sample's acoustic characteristics[11-12]. A stiff backrest is utilized for measuring the absorption coefficient. The recorded data was viewed in the screen by erratic variations of peaks at different frequencies ranging from 500 KHz 3150 KHz. The complete experimental setup for sound absorption tests is visualized in Fig. 5.

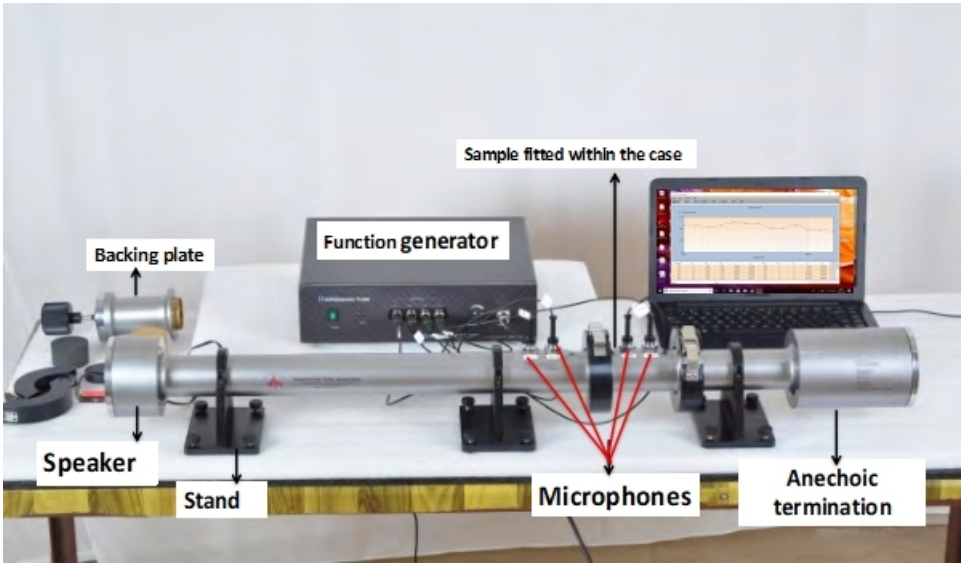


Fig. 5 Impedance tube setup for acoustic measurement

Experimental setup for thermal conductivity

Physical properties like thermal conductivity of Orange peel was calculated with thermal analyzer KD2 PRO with single needle sensor TR-3 with accuracy ±10% designed for composite materials. The TR-3 thermal sensor (2.4mm diameter and 100mm length) uses an infinite line heat pulse technique (ILHP).The device technique is based on ASTM D5334 standard. In order to measure thermal conductivity of the prepared composites a small precise whole was made through the composite using drilling machine. Thermal grease was injected into the whole to configure the sensor needle swiftly without damaging the sensor tip. Thermal conductivity was recorded for different particle size of composites at room temperature. Fig. 6 shows thermal conductivity measurement setup.

Fig. 6 Measurement of thermal conductivity

Result and discussion

Scanning electron microscopic image of orange peel fibre and orange peel fibre composite are shown in Fig.7 (a) and 7(b) respectively where there is a major transformation in the exterior surface to understand the interlocking between fibres for synthesis of composite. From the Fig. 7(a) it is confirmed that a bundle of natural cells are bonded by natural polymers present orange peel like lignin and pectin [13-14]. A large number of void places can be seen in surface of orange peel which are generally lumens that are mostly present in the cells of bio fibres. While Fig. 7(b) shows the morphology of orange peel composite with a presence of large number of active porous site on the surface of the orange peel composite due to slack particle packing of greater particle size of orange peel powder. The composite is filled with multiple tiny holes which indicate its porous nature. There are both open and closed pores. The open pores are open to the external surface while the closed pores are totally isolated[15-17]. The open pores are more efficient than closed pores for absorption of sound. The availability of large number of pores on the surface of the composite and complex elastic skeletal structure enhances the absorption of sound energy incident on the surface of the composite material.

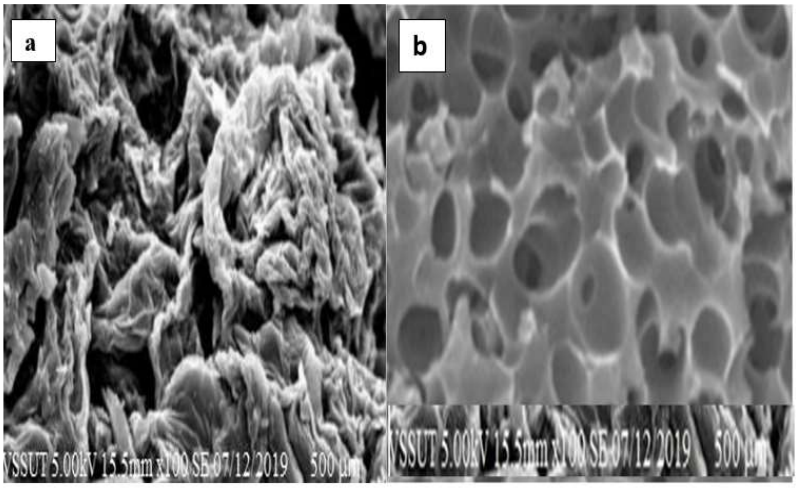
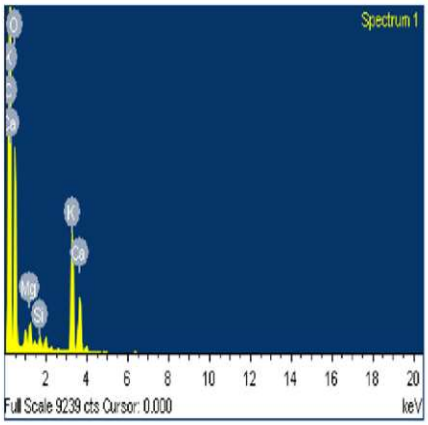


Fig. 7 a SEM of Orange peel **b** SEM of Orange peel Composite

The energy-dispersive X-ray spectroscopy (EDS) of orange peel composite with elemental characterization is shown in Fig. 8. The graph displays the atomic weight percentages and elemental peaks in orange peel fibre. Data are collected in the form of weight % and atomic %. From the EDS data it was observed the predominance of carbon,

oxygen and potassium in orange peel composite. In the orange peel composite the percentage of oxygen is 46.99% which is quite greater than that of other natural fibres. This might be because of existence of additional non-cellulosic constituents in orange peel fibre, such as pectin and callus [18-19]. Following mercerization, the carbon weight % was lowered to 37.37%, but the atomic percentage increased at a similar rate. It might be because the action of surfactant during the treatment process which eliminates hemicellulose, lignin and other cellulosic components. Presence of trace levels of calcium, potassium, and magnesium was detected in the orange peel fibre. The presence of carbon, oxygen and silicon confirms the function as a sound absorber. The existence of oxygen provides the light weight of the sample[20]. The presence of silicon enhances the stiffness property and helps in attenuation of sound.



Element	Weight %	Atomic %
C	36.37	47.22
O	46.99	45.79
Mg	1.29	0.83
Si	0.61	0.34
K	9.54	3.81
Ca	5.2	2.02
Totals	100	

Fig. 8EDX Spectra and elemental wt% of orange peel

A normal impedance tube method was adopted for measurement of sound absorption. As demonstrated in Fig. 9, the sound absorption coefficient increases with the increase in particle size of orange peel inside composite. The absorption at low frequencies is comparatively smaller than higher frequencies. Untreated orange peel composite show lower sound absorption coefficient than ultrasonically treated composite. After 500Hz, the sound absorption coefficient reaches its maximum value. In both cases of treated and untreated Orange peel composite with 300µm particle size shows the highest value for sound absorption coefficient. Orange peel particles are placed randomly in epoxy to provide many empty sites with a significant pore structure that may absorb sound. Basing on the treatment with NaOH, due to the elimination of material with a smaller molecular weight from the fibre surface causes globular pultrusions to disappear from the surface of the orange peel composite creating active sites for perfunctory interlock between fibre and the matrix as a result porosity increases on the material surface[21-22]. Sound inter-reflections occurs within the porous structure present on the surface of the orange peel composite which decreases the airflow resistivity of the composite which results in absorption of sound inside the pores. Sound absorption is also affected by the material's size, number of pores, and nature of pores. The air molecules inside this porous structure are allowed to vibrate freely when the porous side of the composite is subjected to high intensity sound[23]. Thermal energy is generated by these vibrations. As a result, sound energy was converted to heat energy inside the composite. At lower frequencies, the conversion is much smaller, and thus the variations are isothermal, but at higher frequencies, adiabatic changes occurs[24]. The optimal sound absorption coefficient for Orange peel composite of 300 µm particle size in both treated and untreated condition was 0.86 and 0.77 respectively at frequency of 3150Hz. The material may be classified as a Class – B type sound absorber since its absorption coefficient is 0.86, according to the standard SR EN ISO 11654, 2002.

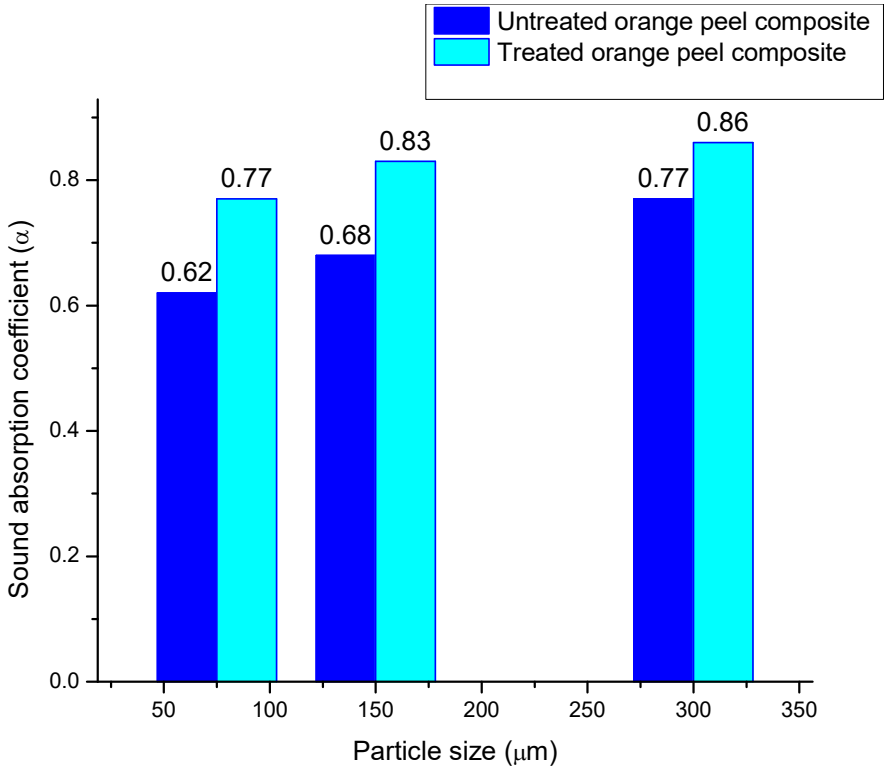


Fig. 9 Sound absorption coefficient of untreated and treated orange peel fibre

The powder sample of orange peel was characterized using FTIR Spectroscopy. Fig. 10 shows the chemical bond of both untreated and treated orange peel fibre where the spectrum depict the distinct bands corresponding to the lignin, cellulose and hemi cellulose of the fibre. From the trend of the spectrum it is clear that that the presence of an extreme stretched band in high energy region is mostly indicate the presence of –O-H- group due to the intra molecular and intermolecular hydrogen bonding of carbohydrate as well as lignin[25-27]. A broad band stretching at 3271.04 cm^{-1} was due to the involvement of hydroxyl group (O-H) of lignin[28]. The peak at 2911.9 cm^{-1} shows C-H stretching vibration of CH_2 and CH_3 groups. C=O stretching is observed at 1736.74 in untreated orange peel where as there is an absence of this spectrum in treated orange peel powder which provides a clear idea about loss of lignin due to chemical treatment[29-30]. Aromatic symmetrical stretching of carbonyl group (C=C) is noted at 1605.6. The peaks from1605.6 to 1012.59 is assigned to lignin containt of the lignocellulosic fibre where the peak at 1229.11 is found due to aromatic skeletal stretching of band and 1012.59 is formed as a result of ring and side group vibration of (C-O-H) group in lignin and (C-O-R) group in hemicellulose[31]. The relative height of OOP absorption peak (801.48) clearly indicates the modification in structure of hemicellulose by destruction of hydroxyl group present on the surface of orange peel powder which increases after chemical treatment[33-35]. The FTIR analysis suggests that all the absorption peaks consigned to loss of lignin, cellulose and hemicellulose were improved after surface treatment with NaOH[36].

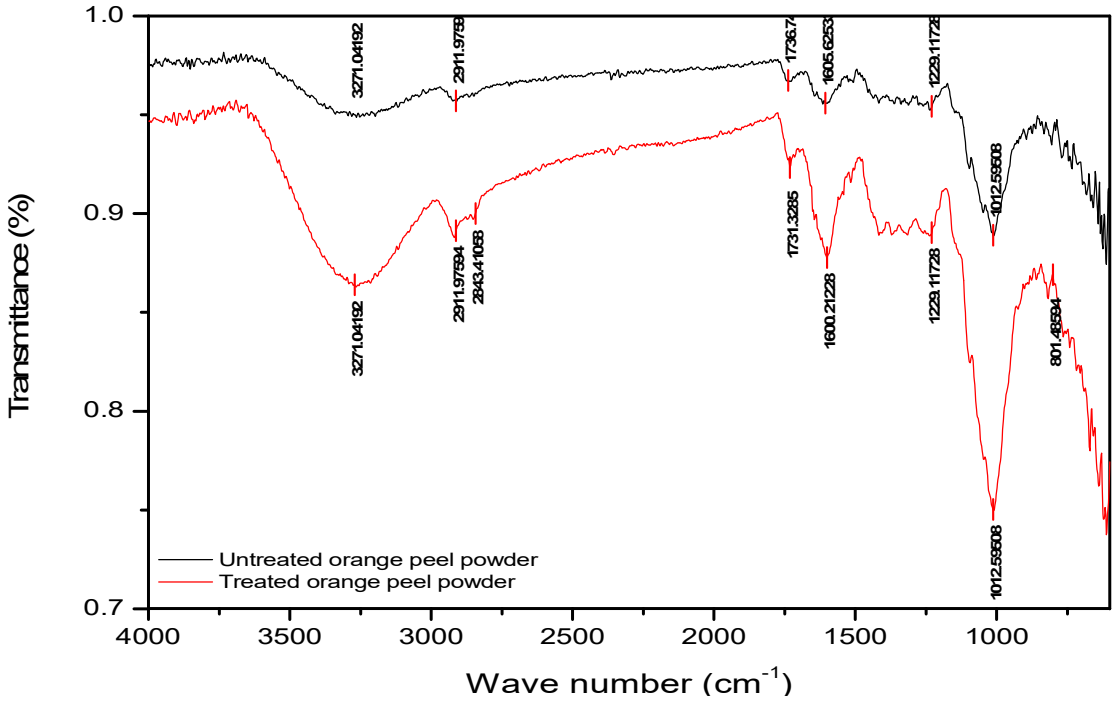


Fig. 10 FTIR spectrum bands of untreated and treated orange peel powder

The X-ray diffraction diffractograms pattern of orange peel is shown in Fig. 11. Peaks in the region of 2θ = 16°, 22°, 34.5º ascend fromhkl planes like (110), (200), and (004) which are planes of cellulose, respectively. This shows that the fibres include cellulose of type I pre and post mercerization[37-39]. The rise in peak intensity of the (200) reflection shows that crystallite size is increasing. Moreover, the slight shift in 2θ from 22.1° towards 22.4° suggests that the chemical modification promotes the conversion of cellulose I_β into cellulose I_α. This process occurs even at lower concentration of NaOH. The raw and treated fiber's crystallinity indices were estimated to be 58 percent and 66 percent, respectively. The findings show that after the process of mercerization, the crystallinity of orange peel fibres increases, potentially facilitating their use in the fabrication of polymer composites.

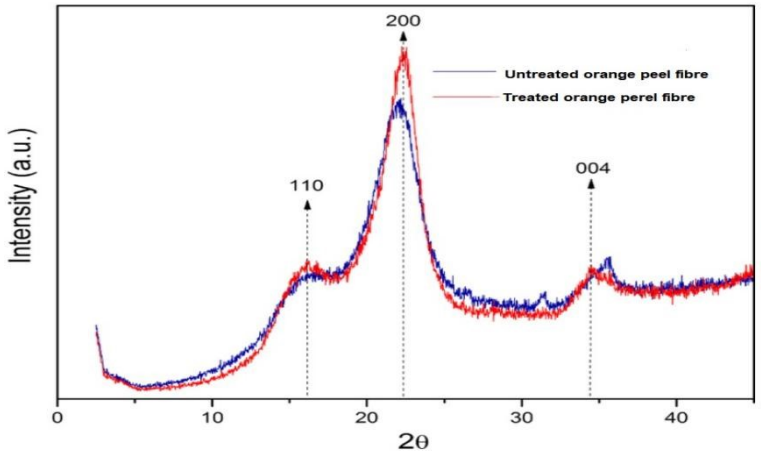


Fig. 11 X-RD pattern of untreated and treated orange peel fibre

The non-uniform dispersion and complex inbuilt networking pattern orange peel within the matrix results in changing the heat conductivity of composite material. Thermal conductivity decreases from 0.0030 $Cal.cm^{-1}.s^{-1}.{}^0C^{-1}$ to 0.0010 $Cal.cm^{-1}.s^{-1}.{}^0C^{-1}$ as the particle size of the orange peel goes on increasing shown in Fig.12. Orange peel composite with 300µm particle size shows the lowest thermal conductivity of 0.0010 $Cal.cm^{-1}.s^{-1}.{}^0C^{-1}$.Thermal

conductivity depend on several parameters, including the nature of the constituents, the interface of the fibre/matrix, the construction and composite geometry [40]. The presence of open and isolated closed void spaces which behaves as elastic skeletal within the composite decrease of thermal conductivity values due to decrease of amplitude of vibration of the particles. In composites, when orange peel are mixed with epoxy polymer dispersed randomly increases the compactness with increase of weight of the composite. The presence of large numbers of pores filled with air makes the material become insulating and the heat exchange takes place slowly as the air is a poor heat conductor [41]. As a consequence, the heat energy produced by the vibration of air molecules inside skeletal structure decreases due to loss of kinetic energy of the particles accommodated within the elastic skeletal wall.

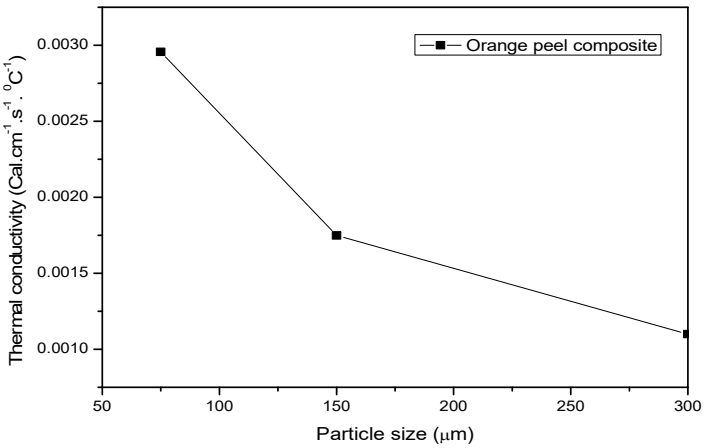


Fig. 12 Thermal conductivity of orange peel composite

Conclusion

With the increase in the detrimental effects of noise pollution on our health and environment, effective sound absorbing material has become the need of the day. The absorber should effectively absorb sound either no negative effects on environment, human health and should be cost effective. If the material is bad conductor of heat then it enhances its usage as it can provide both thermal insulation along with sound absorption. In this report, a study was made on the sound absorption properties of orange peel fiber.It is evident from the surface morphology of orange peel that treated composites show more active sites of fibre and resin interface than untreated composites. The availability of large number of pores on the surface of the composite and complex elastic skeletal structure enhances the absorption of sound energy incident on the surface of the composite material. Based on Energy dispersive spectra (EDS), the elemental composition of orange peel composite consists of carbon, oxygen and potassium which are expressed well in the orange peel-epoxy composite below 20 Kev. The presence of carbon, oxygen and silicon confirms the function as a sound absorber. The existence of oxygen provides the light weight of the sample. The presence of silicon enhances the stiffness property and helps in attenuation of sound.According to the study on chemical mapping using FTIR, the reconstruction of the fibre and elimination of specific contaminants that increased sound absorption was achieved due to the ultrasonic mercerization. The graph confirms that lignin, cellulose, and hemicelluloses were removed by chemical treatment. From the X-ray diffraction diffractograms pattern of orange peel after the process of mercerization, the crystallinity of orange peel fibres increases, potentially facilitating their use in the fabrication of polymer composites. Form thermal properties it is concluded that the composite has ability to absorb heat due to randomization distribution of orange peel particle of different particle size which decreases compactness of the material. Thus during the propagation of sound wave inside the porous structure the incident sound gets dissipated in to heat and this heat is absorbed by the material. The study of the

acoustical characteristics has confirmed the composite's effectiveness and sound absorber. The optimum value of absorption coefficient is 0.77 for the untreated orange peel composite at 3150 Hz frequency and 0.86 for treated composite respectively. It means the treated composite has the potential to absorb 86 % of sound at 3150Hz frequency. It gives good absorption coefficient for higher frequencies while for the lower frequencies the coefficients are lower. The synthesized composite can be used in noisy places as an effective sound absorber and insulation material. It also finds major applications in architectural designing of buildings for civil construction, in defense, automobile spare parts and electrical applications.

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