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# Effect of Sodium Hydroxide (NaOH) Treatment on Coconut Coir Fibre and its Effectiveness on Enhancing Sound Absorption Properties

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## ABSTRACT

Natural fibre has been conventionally and widely utilised as a sound absorber in order to replace the traditional synthetic absorber materials. In this study, coir fibre (CF) was prepared as an acoustic absorber and subjected to an additional surface treatment by using sodium hydroxide (NaOH) at various concentrations ranging from 1% to 8%. This was geared towards analysing the effect of alkalisation on the fibre morphology, diameter, and changes occurring in the CF functional groups, thus resulting in enhanced sound absorption properties. To this end, the fibre surface was analysed using a scanning electron microscopy (SEM) to study the surface morphology of treated and untreated CF materials, whereas the implementation of Fourier-transform infrared (FTIR) allowed an analysis of CF characterisation. The absorber sample was fabricated at a constant thickness of 45mm and a density of 0.4g/cm$^3$ density prior to testing for the sound absorption coefficient (SAC) by using an impedance tube. The morphology of CF revealed the treated fibres to be free of impurities including lignin and hemicellulose layer, which were removed from their surface. This finding was supported by the peak changes observed on the FTIR spectra. Furthermore, the fibre diameter was reduced as the concentrations of NaOH increased. The results conclusively indicated that treated CF at the concentrations of 7% and 8% NaOH gained the highest SAC values across the low and high-frequency ranges, yielding an α coefficient average of 0.9 and above.

*Keywords*: Coir, fiber diameter, fourier transform infrared (FTIR), sodium hydroxide, sound absorption coefficient, surface morphology

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## INTRODUCTION

Today's modern era has resulted in the development of noise from the environment and transportation alike to become a source of pollution for mankind. As noise is inherently present in the physical surrounding, one cannot escape from this element; however, it should be noted that different people are not equally affected by the same noise. Regardless, excessive noise may affect human health and yield different psychological effects, which include insomnia, heart attack, and hypertension (Memon et al., 2015; Shiney & Premlet, 2014). Collectively, these problems lead to public awareness and concerns regarding noise pollution. Following this, demands for a solution in order to counter-act against such issue has been raised, underlining the need for proper noise control to ensure human comfort, especially in a building compartment. To this end, improving the human quality of life and growing general awareness towards the environment have spurred much interest in sustainable materials such as natural fibre by previous researchers as the sound-absorbing materials as opposed to traditional synthetic materials, such as glass wool, minerals fibres, and fibreglass. In fact, the recent decades have been associated with natural fibre and its popularity over synthetic fibre due to its low cost, lightweight attribute, ample supply as a natural and renewable resource, and good mechanical properties (Berardi & Iannace, 2015). This allowing the increasing development of more sustainable materials and support sustainability initiative. Additionally, natural fibre is a fibrous material, which can result in porous sound-absorbing materials offering excellent acoustic absorption attribute at a high-frequency range (Tang & Yan, 2017).

According to Abdullah et al. (2015) higher fibre volume yields better absorptive properties compared to a lesser fibre volume of banana fibre and sugarcane bagasse fibre. Moreover, the combination for both types of fibre show a beneficial outcome in sound absorption improvement compared to a single fibre usage. Meanwhile, Santoni et al. (2019) had assessed the effect of treatment on the physical characteristics of a material and the effect of sound absorption performance when utilising hemp fibre. They found, finer fibre diameter due to the treatment increased the sound absorption coefficient compared to thicker fibre diameter. In another study, Taban et al. (2019) found that coir fibre with thickness 45 mm produced higher sound absorption than thinner sample of 25 mm and 35 mm with SAC value of 0.97 at 1000 Hz. Next, the introduction of air gap during the experimental analysis at 10, 20, and 30 mm resulted in a significantly increased SAC at a low-frequency range. Same observations made by Ying et al. (2016), where the thicker samples and the introduction of air gap exhibited higher sound absorption of coir fibre.

Theoretically, natural fibres are commonly known as a lignocellulosic material predominantly made up of cellulose, which is the most abundant biopolymer component present on earth (Kabir et al., 2012; Naidu et al., 2017). It can also be defined as a fibrous material due to its complex internal structure, thereby forming the cell wall of a plant

(Hassan & Badri, 2014). Despite natural fibre being acknowledged with properties such as good mechanical attributes, easy processing, occupational health benefits, and reduced environmental effect (Chandramohan & Marimuthu, 2011), it is also associated with various well-documented drawbacks. Such disadvantages include moisture absorption, low thermal stability, and poor compatibility with a hydrophobic polymer matrix (Akhtar et al., 2016). To counter-act the aforementioned weaknesses, several studies have opted to investigate the properties of natural fibre for its improvement, namely via natural fibre surface modification by using either physical, chemical, or biological treatment.

Nevertheless, alkali treatment by using sodium hydroxide (NaOH) is well-known as a commonly employed chemical treatment for natural fibre and typically yields good fibre-matrix adhesion and improves the thermal and mechanical properties of composite (Jayabal et al., 2012). The reaction between NaOH and natural fibre is as shown in Equation 1.

$$\text{Cell} - \text{OH} + \text{NaOH} \qquad \text{Cell} - \text{O}^- \, \text{Na}^+ \, H_2O + \text{surface impurities} \qquad (1)$$

Alkali treatment of NaOH eliminate impurities and reduces diameter of fiber by removal the lignin ad hemicellulose layer on fiber surface (Senthamaraikannan & Kathiresan, 2018). Despite, NaOH treatment would also maximize the mechanical strength of kenaf fibre and PALF reinforced composites (Feng et al., 2020). Using 5% of NaOH solution, alkali-treated Ziziphus Mauritiana fibers improved on the surface roughness and influenced the bonding behavior due to the reduction of amorphous constituents (Vinod et al., 2020).

Therefore, this current work focus to find an alternatate materials which was sustainable to replace synthetic sound absorber. Although a number of studies has been devoted towards exploring the usage of natural fibre as a sound absorber, the effect of its surface treatment via NaOH across different concentrations is seldom reported, especially in the context of Malaysian natural fibre and natural fibre waste. Hence, this paper attempts to observe the morphological changes of coir fibre structure and its fibre diameter changes after being subjected to NaOH treatment in order to enhance the sound absorption properties of coconut coir fibre (CF).

## MATERIALS AND METHODS

### Material Preparations

Raw CF was supplied by a local agricultural waste supplier, namely Sarjani Agro Shop Sdn. Bhd. located in Sri Medan, Batu Pahat. The CF sample was then cut to a shorter length of ± 2 cm to 5 cm for easy processing during the fabrication stage. To analyse the morphological and chemical changes occurring in the fibre structure and their effects towards sound absorption performance, the CF sample was treated using NaOH of different concentrations. Therefore, the control sample consisted of untreated coir fibre, while eight different concentrations of NaOH were utilised, namely 1%, 2%, 3%, 4%, 5%, 6%, 7%, and 8%, respectively. Next, the fibre-to-solution ratio was set to 1:20 so as to ensure the fibres were fully submerged in the NaOH solution and soaked for two hours. Following this, they were washed under running water for several times to eliminate any NaOH residue on the fibre strands, until no change in colour was observed in the drained water. Subsequently, the process of drying the fibres commenced, which was done under the sun for 2 to 3 days depending on the weather condition, before they were oven-dried for 30 minutes at the heating temperature of 110°C ± 5°C.

**Sample Preparation**

In this study, 15% of urea formaldehyde (UF) was utilised as the main adhesive material for the formation of the acoustic samples (Nasidi et al., 2018). It was provided by Evergreen Adhesive & Chemical Sdn. Bhd., which is a prominent company specialising in wood-working adhesives and located at Parit Raja, Batu Pahat, Johor. Then, the CF sample was fabricated at a constant density of 0.4 g/cm$^3$ and 45 mm thickness (Samsudin et al., 2017). In particular, two sample diameters were fabricated, specifically 28 mm and 100 mm, which were then fit into the prepared mould and compressed by using a hot compression machine for 15 min at 180°C using 1000 psi. Following this, the samples were removed from the machine and left at room temperature for cooling down (Figure 1), it should be noted that this was done before they were taken out from the mould to prevent any damage. In total, six samples (three samples for the 29 mm diameter and theree samples for 100 mm diameters) for each concentration were subjected to testing in the impedance tube to determine their respective acoustic absorption coefficient.

*Figure 1*. CF sample

**Fibre Diameter**

The diameter measurement of CF samples was carried out by using a Digital Microscope Image Analyser, whereby 100 single-fibre strands were randomly selected for each concentration of treatment. Due to their irregular shapes, measurement of a single fibre was carried out in three positions, namely at the top, middle, and bottom of the fibre (Sanjay et al., 2019). Every fibre measured was cut according

*Figure 2*. CF under Digital Microscope Image Analyser

to the average length of each fibre type in order to calculate its average diameter at the three aforementioned positions to yield the actual fibre diameter. Figure 2 shows the CF diameter measurement conducted using the Digital Microscope Image Analyser.

### Surface Morphology Analysis

The element of CF surface morphology was examined in this study by employing a scanning electron microscopy (SEM) using HITACHI SUI510 model. Prior to observation, the samples were coated with gold three times for 90 s. Following this, the surface morphology analysis was carried out with an accelerating voltage of 15 kV and 63.0 uA emission, whereas the observation was undertaken at 500× magnification focused on the fibre structure and silica bodies present on its surface.

### FTIR Analysis

Fourier-transform infrared (FTIR) is a cost-effective, rapid, non-destructive, simple, and appropriate tool for analysing the changes in fibre functional groups, whether in untreated or treated fibres alike. To this end, untreated and treated CF spectra were determined accordingly using Perkin Elmer FTIR Spectrometer LR 64912C, N3896, FTIR software V1.3.2 Perkin Elmer LX100877-1 made in the U.S.A., which was equipped with an ATR sample holder. To achieve this, the CF samples were ground into powder form less than 100 microns, which was next inserted into the powder plate until it covered the crystal glass and was slowly compacted. The process was carried out at a wavenumber ranging between 4000 $cm^{-1}$ to 600 $cm^{-1}$ and operated at a resolution of 4 $cm^{-1}$, whereby 32 scans were collected for each sample.

### Sound Absorption Test

The next phase consisted of CF sample measurement by using an impedance tube in accordance to BS ISO 10534-2 in order to measure the sound absorption coefficient (SAC). This equipment and its method of measurement are well-known as a simple approach, which is easily conducted and convenient in determining the $\alpha$ value. Measurement equipped with tubes (SCS9020B/TL), two-unit microphones, one speaker and one computer to analyse the data. The process was carried out within the range of frequency from 100 Hz to 5000 Hz in 1/3 octave band. In particular, the low-frequency range testing employed a large tube with a 100 mm tube diameter at the frequencies spanning from 100 Hz to 1600 Hz, whereas high-frequency range testing spanned from 1500 Hz to 5000 Hz by using a small tube with a 29 mm diameter tube size . Then, measuring the absorption coefficient in order to assess the sound absorption performance was done by placing a loudspeaker at one end of the impedance tube and a sample at its other end. During the testing, the sound waves were propagated within the tube to strike between the sample and sound source, which then reflected as a standing wave.

## RESULT AND DISCUSSION

### Coir Fibre Diameter

Table 1 details a summary of the results obtained from laboratory measurements of the CF diameter. Physically, CF revealed an almost regular diameter along the entirety of the fibre strands. However, the measurement was also taken at three different locations of the strand, allowing the calculation of a mean value. The values in Table 1 reveal a larger fibre diameter for the untreated CF sample compared to the treated fibre. In particular, untreated CF yielded an average diameter ranging between 46.7 μm and 260.0 μm, whereas its average diameter value was 124.27 μm. A similar result had been reported by Chen et al. (2016) when bamboo fibres were subjected to varying concentrations of NaOH, while studies by Dittenber and Gangaroa (2012) and Geethamma et al. (1998) had observed their raw CCF diameter that ranged from 100 μm to 460 μm. Next, the mean CF diameter was reduced after the samples were treated with different concentrations of NaOH, which spanned from low to high concentrations. In particular, the diameter value was reduced by approximately 22.9 % when its values were juxtaposed across untreated fibre to those subjected to 8% NaOH concentration. Such decrement in fibre diameter is typically caused by the removal of lignin, which is generally found on the fibre surface (Hashim et al., 2017). This is supported by Pouriman et al. (2017), whereby the average diameter of a single salogo fibre was reduced from 6.23 μm to 4.23 μm. Similarly, the alkali treatment subjected to the sample had removed some of the cellulose and lignin contents on the fibre structure, thereby causing the fibre diameter reduction.

Figure 3 depicts the cumulative distribution of 100 fibre strands of CF. The findings clearly showed a decreased fibre diameter when the alkali concentrations were increased. Furthermore, untreated fibre and those subjected to 1% NaOH resulted in a larger fibre diameter, whereby the line in Figure 4 is located slightly to the right side. Meanwhile, fibres treated with 2% and 3% NaOH straddled the middle range between the thicker and thinner fibre diameters, whereas NaOH concentration increments from 4% to 8% yielded barely-seen changes in the fibre diameter. However, it should be noted that the 7% and 8% NaOH concentrations were characterised with graph lines located at the outer part of the group on the left side.

Table 1
*Range of diameter and average diameter of untreated and treated CCF samples*

| Fiber | CF 0% | CF 1% | CF 2% | CF 3% | CF 4% | CF 5% | CF 6% | CF 7% | CF 8% |
|---|---|---|---|---|---|---|---|---|---|
| Range of diameter (μm) | 46.7–260.0 | 36.7–346.7 | 40.0–306.5 | 30.0–270.0 | 30.0–261.2 | 36.9–260.8 | 36.2–216.7 | 20.0–326.7 | 26.7–360.1 |
| Average Diameter (μm) | 124.3 | 123.9 | 112.9 | 105.9 | 104.8 | 103.4 | 101.1 | 98.8 | 95.8 |

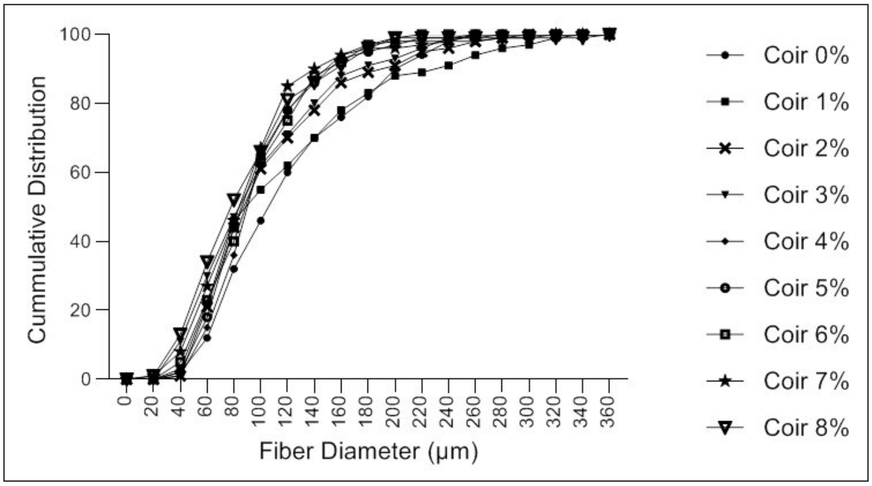


*Figure 3*. Cumulative distribution of CF

## Surface Morphology of CCF

Figures 4 (a) - (i) reveal the surface morphologies of untreated and treated CF samples ranging from 1% to 8% NaOH concentrations, which were analysed using SEM. For example, the untreated CF fibre strand is shown in Figure 4(a) in which it is fully covered by impurities and has uneven surfaces. Besides, its components included pectin, wax, lignin, and silica bodies, which paralleled the observations of Ng et al. (2018). Removal of impurities could be seen as compared to the untreated fibers. It shows gradual changes in the effect of NaOH treatment on the coir fiber surface. Meanwhile, treated CCF samples subjected to NaOH concentrations ranging from 1% to 3% (Figure 4 (b)-(d)) showed a partial removal of the impurities, including silica bodies, which left tiny holes on the sample surfaces. These tiny holes are associated with the creation of microcompartments, which are good for sound dissipation purposes (Mercado et al., 2018). Therefore, this shows that a low concentration of NaOH does not significantly affect the removal of impurities present on the fibre (Hashim et al., 2017). Subsequently, an increased concentration of NaOH treatments subjected to higher concentrations from 4% (Figure 4(e)) to 6% (Figure 4(g)) allowed the remaining silica bodies to be completely removed. As a result, it created pores that appeared due to the removal of the silica bodies, which looked larger with an uneven depth. Similar findings had also been discovered by Ng et al. (2018), which further increased the mechanical bonding between the coir fibre and matrix during the fabrication proces (Karthikeyan et al., 2014). Additionally, some longitudinal pits were observed along the fibre strands assessed in this study, thereby paralleling the same phenomenon described by (Manjula et al., 2017). However, as the NaOH concentrations increased to 7% and 8% (Figure 4 (h)-(i)), these previously created pores disappeared almost completely. This may be attributable to the surface layer CF removal (Leão et al., 2015) Besides, the morphological results indicated the CF fibres had rough surfaces and were clean from any impurities as the NaOH concentration was increased. To support the argument regarding alkali treatment effectiveness, FTIR spectroscopy was employed to investigate the structural changes observed on the CF sample surface before and after treatment.

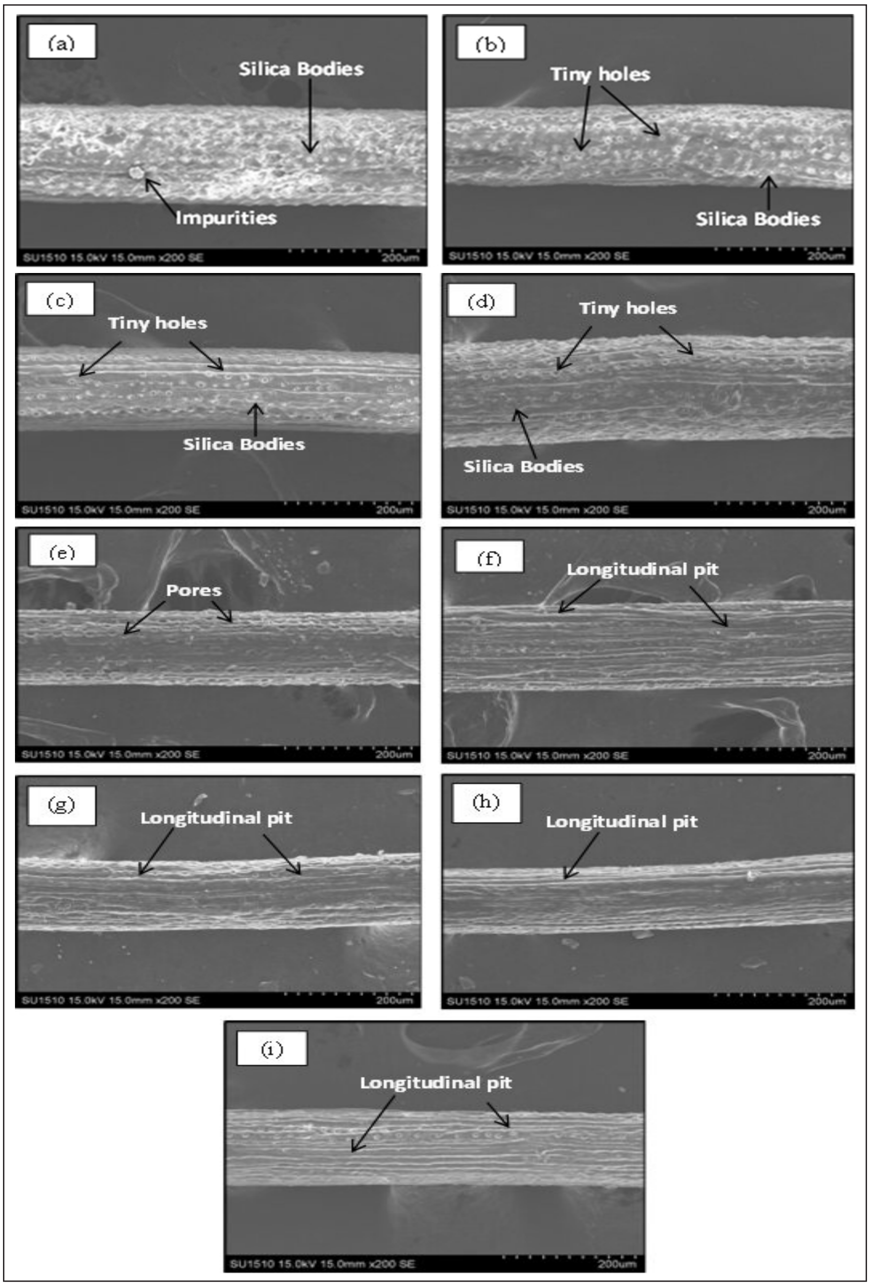


*Figure 4*. SEM images on surface of CF : (a) CF0%, (b) CF1% (c) CF2%, (d) CF3%, (e) CF4%, (f) CF5%, (g) CF6%, (h) CF7%, and (i) CF8%

## FTIR Analysis

Figure 5 represents the FTIR spectra observed for the untreated and treated CF samples, ranging from 1% to 8% concentrations. First, the peak ranging from 3000 $cm^{-1}$ to 3700 $cm^{-1}$ corresponded to the O – H stretching of hydroxyl groups (Krishnan & Ramesh, 2013; Siakeng et al., 2018). In this study, the untreated CF gained its O – H peak at band 3345 $cm^{-1}$ in which the observations clearly and contrastingly depicted a significantly reduced intensity for alkali-treated sample. The diminished intensity may be attributed to the breaks of hydrogen bonding present in OH groups during the NaOH treatments (Yew et al., 2019). Meanwhile, the absorption band corresponding to the C = O stretching of carboxyl and acetyl groups in the hemicellulose yielded the raw CF peak band at 1735 $cm^{-1}$. However, it disappeared when the fibres were treated with NaOH, which could be linked to hemicellulose solubility property in an alkaline solution and thus caused its disappearance (Yew et al., 2019). The same observations had also been made by Abraham et al. (2013), wherein a peak was present at band 1249 $cm^{-1}$ for the untreated CF sample and attributable to the aromatic ring skeletal vibration and C = O stretching of lignin. However, the peak for treated fibre samples was not completely removed; its intensity was merely decreased. Therefore, this is indicative of some lignin and hemicellulose content removed via the NaOH treatment from the fibre surfaces and supports the fibre diameter decrements outcomes observed after subjected to the treatment.

## Sound Absorption Coefficient (SAC)

Figure 6 illustrates the sound absorption performance generated by untreated and NaOH-treated CF samples, which range from 1% to 8%. The findings revealed that as the frequency increased, the SAC values were also amplified in line with the outcomes from (Taban et

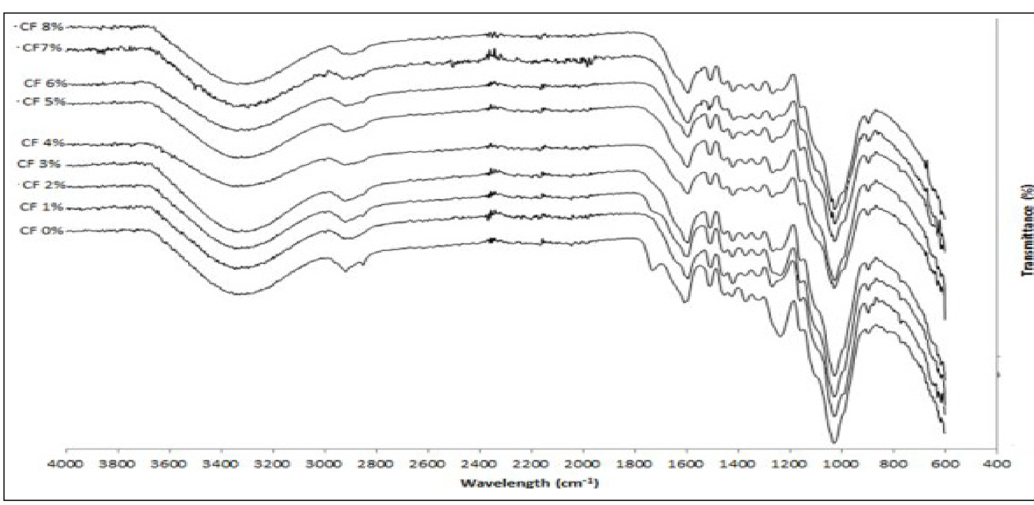


*Figure 5*. FTIR spectrum of raw and alkali treated CF

al., 2019). Furthermore, the result shows that from, untreated and treated CF samples alike yielded superior acoustic absorption ability at the frequency ranging from 500 Hz to 5000 Hz. Besides, the SAC values obtained for all samples were higher than 0.5, thereby indicating that over 50% of the incident sound was absorbed. The figure further shows that the peak absorption at a lower frequency region is gained by CF samples treated with high NaOH concentrations. In particular, samples subjected to 7% and 8% NaOH yielded $\alpha$ = 0.98 at the frequency of 1250 Hz. Upon entering the middle frequency region, the SAC value for all CF samples was decreased, revealing the least absorptive value as low as 0.72. In contrast, the highest sound absorption performance was obtained by an untreated CF sample in the middle frequency range, indicating its status as a good absorber from the middle to the beginning of the high-frequency range in comparison with treated fibres. Here, the SAC values recorded ranged from 0.83 to 0.96 at frequencies between 2000 Hz to 4000 Hz. Lastly, the high-frequency sector revealed the highest SAC values obtained at the higher NaOH concentrations (i.e. 7% and 8%), while other samples also observed an increased sound absorption performance. This outcome is significantly attributable to the finest diameter of fibre treated with the highest NaOH concentrations through the removal of impurities, lignin and hemicellulose layer on fiber surfaces, thus enhancing the SAC outcomes at the low and high-frequency ranges (Wang et al., 2015). Similar outcome was discovered by Samaei et al. (2020), where the decrement on fiber diameter due to NaOH treatment increased the sound absorption performances of kenaf fiber at constant thickness and density. Theoretically, fiber diameter was the one factor that influencing the sound absorption of fibrous materials. This was due to the more tortuous path and higher airflow

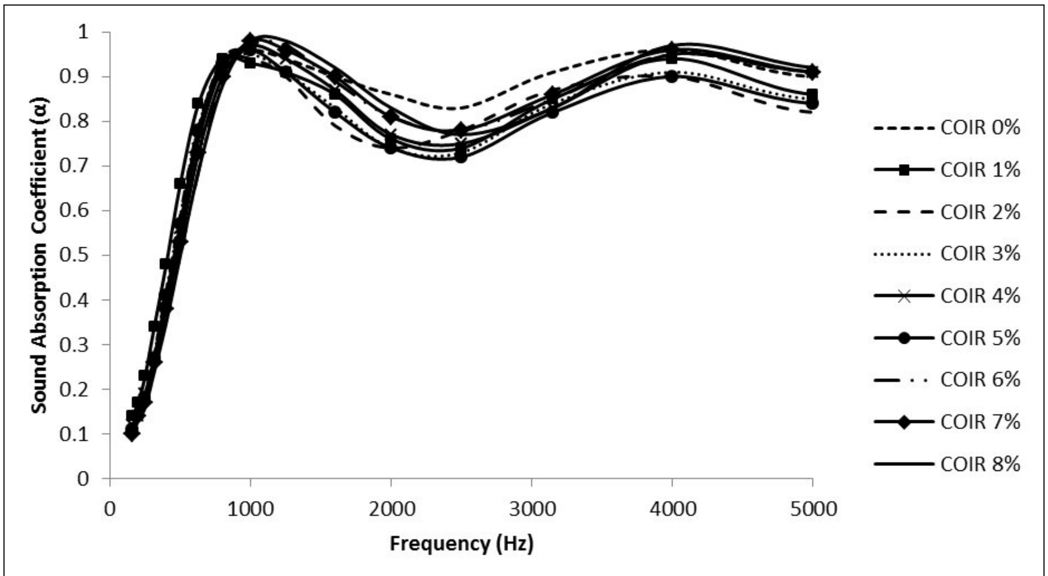


*Figure 6*. Sound absorption performance of CF at different concentrations of NaOH treatment

resistance caused by higher fibre volume needed to reach equal volume of fibre with same thickness and density (Seddeq, 2009). Further analysis was made to see the correlation between acoustical performances and fibre diameter of coir fibre. It was observed that there was a positive correlation between the two variables where r = 0.754. Overall, CF implementation led to good absorption performance and the material was thus considered a good absorber.

## CONCLUSION

In this work, CF was utilised as a sound absorber material, whereby its surface fibre was subjected to treatment using 1% to 8% NaOH concentrations. Accordingly, the morphological changes, fibre diameter, and fibre composition were observed and analysed in evaluating its characteristics and sound absorption performance. In brief, NaOH-treated CF samples yielded enhanced sound absorption performances in comparison with the untreated sample, whereby a higher NaOH concentration led to better performance. This is caused by its finer fibre diameter in which an absorber sample requires a higher amount of fibre to have the same weight as a thicker fibre sample, thus allowing more sound energy to be dissipated. Furthermore, the average fibre size decreased when the alkali concentrations were increased, whereas the surface morphology analysis revealed the partial removal of certain impurities at a certain amount from the fibre surface, which included lignin and hemicellulose. Up until 8% NaOH concentration, clear fibre was observed and supported further by the accompanying FTIR peak spectra results. Hence, the results obtained in this study suggested for the use of 7% and 8% NaOH concentrations in order to optimally implement a coconut fibre treatment approach geared for maximum sound absorption performance.

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