Indian Journal of Engineering & Materials Sciences
Vol. 30, February 2023, pp. 112-121
DOI: 10.56042/ijems.v1.148842

# Fabrication of green composites by waste coconut shells as partial replacement of coarse aggregates in concrete and determination of its acoustic behaviour

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*Received: 14 April 2021; Accepted: 6 Decmeber2022*

Nowadays, natural materials have been frequently used for sound absorption in constructions and buildings. This paper has characterised the acoustic behaviour of coconut shell reinforced concrete composite with partial substitution of coarse aggregates in terms of sound absorption at octave frequency signals (32 Hz-16 kHz). Composites have been prepared in different weight percentages (5%, 10%, 15%, and 20%) of partial substitution of coarse aggregates. The acoustic test has been conducted in a 3.5 mm thick glass box without and with samples by point method of sound power measurement. The results have demonstrated that the value of the sound pressure level has decreased at different points with the increased percentage of coconut shells in composite, hence increasing the sound absorption coefficient of the concrete. The results have also been compared with conventional concrete composite. Additionally, the results have indicated that these concrete blocks can significantly absorb sound in the mid-frequency range. Generally, a sound absorption coefficient greater than 0.2 for any material qualifies it as a sound-absorbing material, and a sound absorption coefficient greater than 0.6 for any material is known as the best sound absorber. Therefore, developing such green composites can be an eco-friendly approach to the acoustic community.

**Keywords:** Concrete, Coconut shell, Point method, Sound absorption coefficient, Sound power level

## 1 Introduction

Concrete has the second most consumable material after water[1] and has been used for several applications, such as buildings, industries, dams, and other structural applications. There have been numerous concretes such as reinforced concrete, fiber reinforced concrete, foam cellular concrete, silica fume concrete, limecrete, glass concrete, polymer concrete, asphalt concrete, green concrete, ultra-high-strength concrete, lightweight concrete, etc. The concrete has been produced by the chemical reactions between cement and water and has been firmly mixed with fine and coarse aggregate. The percentage of various compositions in concretes has coarse aggregates (42%), fine aggregates (26%), water (16%), cement (12%), and air (4%)[2]. The aggregates occupy asignificant volume of concrete, and in general, these consist of gravel, sand, and stones, which have properties such as better hardness, firmness, and durability[3]. The depletion rate of aggregates has increased because of their continuous extraction from natural resources. Moreover, the process involved during the extraction of these aggregates has not been eco-friendly. Hence, these conventional aggregates can be substituted by construction waste (demolished concrete, glass, plastics, etc.)[4], plastics waste (packaging films, wrapping materials, garbage bags, etc.)[5,6], polymer waste (ethylene vinyl acetate)[7], rubber waste (tire)[8,9], glass waste (flat glass, bulb glass, bottle glass, etc.)[10], and agricultural by-product waste (coconut fiber[3,11], coconut shell[12,13], oil palm shell[14], etc.) in the form of coarse and fine aggregate in concrete. The agricultural by-product has been one such alternative to developing sustainable green concrete. The utilization of agricultural by-products in concrete has resolved the problem of disposal of these materials and helped to maintain an eco-friendly environment. Coconut shells (CS)have been an important agricultural waste and have been produced during the processing of the coconut crop[15]. It has been available in tropical countries of the world[16]. India has held the 3rd position globally with an annual production of

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approximately 11 billion nuts[17]. Being a spiritual country CS have generated a large amount of waste from temples daily. Additionally, there have been several industries of coconut product that produces a large amount of waste CS. Such an abundance of waste CS have created an appreciable disposal problem. The CS have been thrown away near beaches, vacant lots, burnt, or dumped in the land. This problem has been resolved by the utilization of waste CS as partial aggregates in concrete. The CS in concrete has met the acceptable strength criterion for structural concrete[18]. As per the studies[19,20], the mechanical properties, bond properties, and long-term performance of CS aggregate concrete have been in the acceptable range for structural applications. Moreover, there have several characteristics of CS, such as high strength and modulus, good impact resistance, better workability, high lignin content (weather resistant), low cellulose content (absorbs less moisture), etc.[1], which has made it anappropriate partial replacement of coarse aggregate in concrete. Substitution of aggregates in conventional concrete has improved not only the mechanical properties but also the acoustical properties. Some examples of such concretes have been concrete mixed with waste tire rubber[8], concrete panels with crumb rubber[9], concrete containing oil palm shells[14], concrete modified with an asphalt/ styrene-butadiene emulsion[21], etc. This paper has aimed to partially substitute conventional concrete aggregates with CS aggregates (wt. percent of 5%, 10%, 15%, and 20%) to construct light weight CS concrete composite (CSCC). The other objectives of this paper have to investigate the acoustic behaviour of samples using the point method of sound power measurement and recycling the CS wastes.

## 2 Materials and Methods

This study used the CSCC of M25 grade in a 1:1:2 (cement: sand: coarse aggregate) ratio. Ordinary Portland Cement, water, natural sand, coarse aggregates, and a mixture of coarse and crushed coarse coconut aggregates were used as materials for fabricating CSCC. The average sand and coarse aggregate sizes were 0.6-2 mm and 10-12 mm, respectively. The standard sieves confirmed the size of sand and coarse aggregates. In this work, the blocks of CSCC samples were prepared in different percentages 5%, 10%, 15%, and 20%. The conventional concrete block was also prepared for comparison. The CS were collected randomly from nearby temples of Prayagraj, India, and crushed into smaller pieces by mechanical means. The terminologies of fabricated samples were 0% i.e. pure concrete composite (PCC), 5% coconut shell concrete composite (CSCC_5), 10% coconut shell concrete composite (CSCC_10), 15% coconut shell concrete composite (CSCC_15), and 20% coconut shell concrete composite (CSCC_20). The demonstration box was made of float glass with a dimension of 200 mm cube and 3.5 mm thickness and was named an empty glass box (Empty).

Generally, the sound power measurement was accepted as per ISO 9614 standards. It contained two parts, the first was ISO 9614-1 for the point method, and the second was ISO 9614-2 for the scanning/ sweep method. This paper used the point method to measure the sound pressure level (SPL) because of its stable and precise results[22]. This method did not require expensive facilities such as impedance tubes and anechoic or reverberation chambers. Also, this technique easily tolerated the steady background noise level during the measurements. The sound power level was calculated with the help of SPL Eq. (1)[23].

$$L_w = L_p - 10\log_{10}\left(\frac{Q}{4\pi r^2}\right) \quad ..(1)$$

where, $L_w$ was the sound power level, $L_p$ was SPL,$Q$ = 2was the directivity factor, and $r$ was the distance from the source.

This method calculated the SPL in four planes (P1, P2, P3, and P4) and at 18 points (P11 to P14, P21 to P24, P31 to P35, and P41 to P45), as shown in Fig. 1. Furthermore, the planes were defined at different distances, 0, 100, 200, and 300 mm from the sound source, to study the effect of the distance on SPL determination. The sound pressure was measured at r = 150, 170, 210, and 290 mm at P1, P2, P3, and P4 planes, respectively, from the sound source. A portable Bluetooth speaker (Sony SRS-XB12) was used as the sound source for this setup. The audio signal was generated through Scilab software, and the SPL (dB) was measured by the sound level meter (indi6182). The sound absorption coefficient (SAC) was defined as the ratio of the absorbed sound to the incident sound and was calculated by Eq. (2).

$$SAC\ (\alpha) = \frac{(L_w)_{absorbed}}{(L_w)_{incident}} \quad \ldots(2)$$

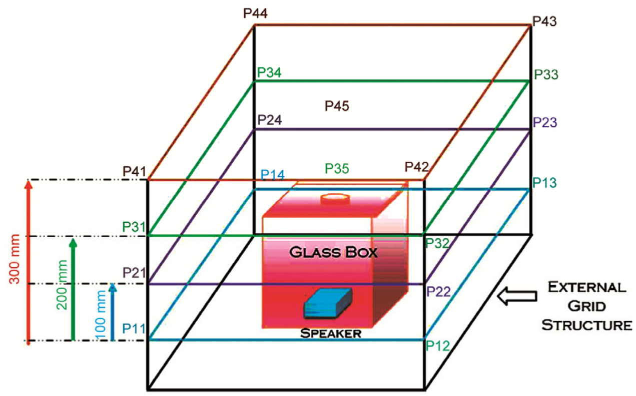

Fig. 1 — Schematic of point method of sound measurement setup.

## 3 Results and Discussion

This study assessed the acoustic behaviour of conventional (PCC) and CSCC in a 3.5 mm thick glass box by point method. The empty glass box's SPL was also measured and taken as a reference for other materials to evaluate acoustic behaviour. The SPL and the SAC were estimated at each corner of the glass box in all four planes. The plane-wise variation of SPL foreach material was given in Tables 1-6.

### 3.1 Variation in SAC at Plane 1

Figure. 2(a-d) showed the variation SAC for the frequency signals, without and with samples (PCC,

Table 1 — SPL for the empty glass box

| Planes | | 32.5 | 65 | 125 | 250 | 500 | 1000 | 2000 | 4000 | 8000 | 16000 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Frequency (Hz) / SPL (dB) | | | | | | | | | |
| P1 | P11 | 53.14 | 78.56 | 81.46 | 81.49 | 88.74 | 89.32 | 87.21 | 85.31 | 71.54 | 51.55 |
| | P12 | 53.16 | 78.54 | 81.14 | 81.70 | 88.53 | 89.10 | 86.20 | 85.04 | 71.90 | 51.45 |
| | P13 | 53.54 | 78.98 | 81.15 | 81.82 | 88.29 | 88.75 | 87.59 | 85.10 | 71.20 | 51.48 |
| | P14 | 53.19 | 78.75 | 81.17 | 81.69 | 88.67 | 89.62 | 86.46 | 85.44 | 71.60 | 51.59 |
| P2 | P21 | 51.95 | 78.88 | 82.39 | 81.20 | 87.02 | 90.81 | 85.55 | 85.52 | 71.90 | 50.54 |
| | P22 | 51.46 | 78.96 | 82.78 | 81.58 | 87.45 | 89.99 | 85.84 | 85.09 | 72.04 | 51.18 |
| | P23 | 51.74 | 78.72 | 82.85 | 81.75 | 87.13 | 90.04 | 85.00 | 85.32 | 71.71 | 50.75 |
| | P24 | 51.56 | 78.84 | 83.82 | 81.25 | 87.63 | 90.69 | 85.16 | 85.65 | 71.73 | 50.96 |
| P3 | P31 | 53.14 | 82.24 | 87.29 | 87.68 | 91.10 | 94.48 | 90.66 | 92.45 | 76.45 | 53.51 |
| | P32 | 53.59 | 82.32 | 87.80 | 87.65 | 91.42 | 94.9 | 90.47 | 92.87 | 76.07 | 53.93 |
| | P33 | 53.87 | 82.41 | 87.45 | 87.45 | 91.66 | 94.10 | 90.68 | 92.95 | 76.46 | 53.55 |
| | P34 | 53.55 | 82.35 | 87.08 | 87.82 | 91.96 | 94.77 | 90.10 | 92.38 | 76.33 | 53.16 |
| | P35 | 58.78 | 87.56 | 95.06 | 95.29 | 96.42 | 98.33 | 94.2 | 98.88 | 85.45 | 58.67 |
| P4 | P41 | 52.19 | 81.45 | 86.60 | 87.39 | 90.94 | 93.21 | 89.78 | 90.86 | 75.04 | 52.64 |
| | P42 | 52.85 | 81.24 | 86.80 | 87.81 | 90.42 | 93.56 | 89.45 | 91.40 | 75.69 | 52.30 |
| | P43 | 52.38 | 81.69 | 86.39 | 87.77 | 90.12 | 93.16 | 89.16 | 90.95 | 75.54 | 52.45 |
| | P44 | 52.24 | 81.15 | 86.19 | 87.43 | 90.65 | 93.87 | 89.61 | 90.66 | 75.65 | 52.74 |
| | P45 | 57.25 | 86.75 | 93.50 | 95.78 | 94.52 | 99.19 | 95.64 | 94.71 | 80.52 | 57.84 |

Table 2 — SPL for the PCC

| Planes | | 32.5 | 65 | 125 | 250 | 500 | 1000 | 2000 | 4000 | 8000 | 16000 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Frequency (Hz) / SPL (dB) | | | | | | | | | |
| P1 | P11 | 50.37 | 75.57 | 78.59 | 78.5 | 85.14 | 77.98 | 75.64 | 72.91 | 67.79 | 49.84 |
| | P12 | 50.19 | 75.24 | 78.08 | 78.87 | 85.25 | 77.82 | 75.60 | 72.59 | 67.19 | 49.81 |
| | P13 | 50.52 | 75.87 | 78.94 | 78.34 | 85.6 | 77.68 | 75.76 | 72.57 | 67.84 | 49.93 |
| | P14 | 50.69 | 75.63 | 78.72 | 78.57 | 85.86 | 77.39 | 75.70 | 72.12 | 67.78 | 49.15 |
| P2 | P21 | 49.2 | 75.38 | 78.08 | 78.78 | 85.22 | 77.24 | 75.81 | 72.28 | 67.15 | 49.45 |
| | P22 | 49.59 | 75.45 | 78.28 | 78.81 | 85.92 | 77.19 | 75.78 | 72.86 | 67.10 | 49.61 |
| | P23 | 49.36 | 75.96 | 78.45 | 78.46 | 85.43 | 77.90 | 75.69 | 72.78 | 67.81 | 49.30 |
| | P24 | 49.57 | 75.31 | 78.76 | 78.69 | 85.15 | 77.13 | 75.20 | 72.48 | 67.97 | 49.84 |
| P3 | P31 | 51.71 | 79.80 | 83.45 | 83.25 | 90.06 | 82.15 | 80.74 | 77.25 | 72.25 | 51.60 |
| | P32 | 51.55 | 79.81 | 83.15 | 83.42 | 90.67 | 82.42 | 80.90 | 77.89 | 72.64 | 51.00 |
| | P33 | 51.87 | 80.04 | 83.54 | 83.46 | 90.33 | 82.37 | 80.73 | 77.72 | 72.48 | 51.53 |
| | P34 | 51.12 | 80.26 | 83.84 | 83.95 | 90.12 | 82.05 | 80.19 | 77.60 | 72.01 | 51.05 |
| | P35 | 56.72 | 85.25 | 88.59 | 88.52 | 95.14 | 87.09 | 85.61 | 82.26 | 77.45 | 56.04 |
| P4 | P41 | 50.53 | 79.35 | 82.45 | 82.14 | 89.45 | 81.65 | 79.01 | 76.56 | 71.25 | 50.12 |
| | P42 | 50.09 | 79.45 | 82.45 | 82.02 | 89.15 | 81.45 | 79.24 | 76.62 | 71.12 | 50.75 |
| | P43 | 50.86 | 79.94 | 82.16 | 82.56 | 89.14 | 81.11 | 79.40 | 76.94 | 71.25 | 50.63 |
| | P44 | 50.89 | 79.15 | 82.94 | 82.53 | 89.38 | 81.45 | 79.89 | 76.57 | 71.89 | 50.36 |
| | P45 | 55.16 | 84.65 | 87.69 | 87.64 | 93.25 | 86.59 | 84.25 | 81.56 | 76.24 | 55.07 |

Table 3 — SPL for the CSCC_5

| Planes | | 32.5 | 65 | 125 | 250 | 500 | 1000 | 2000 | 4000 | 8000 | 16000 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Frequency (Hz) | | | | | | | | | |
| | | SPL (dB) | | | | | | | | | |
| P1 | P11 | 49.38 | 74.40 | 77.26 | 77.14 | 84.45 | 72.12 | 70.36 | 67.15 | 65.45 | 48.59 |
| | P12 | 49.93 | 74.36 | 77.13 | 77.59 | 84.90 | 72.65 | 70.05 | 67.41 | 65.71 | 48.63 |
| | P13 | 49.57 | 74.26 | 77.41 | 77.49 | 84.31 | 72.56 | 70.41 | 67.87 | 65.43 | 48.73 |
| | P14 | 49.56 | 74.02 | 77.28 | 77.59 | 84.01 | 72.33 | 70.65 | 67.15 | 65.73 | 48.23 |
| P2 | P21 | 48.52 | 74.29 | 77.98 | 77.91 | 84.02 | 72.05 | 70.78 | 67.98 | 65.81 | 48.85 |
| | P22 | 48.68 | 74.58 | 77.63 | 77.48 | 84.64 | 72.14 | 70.86 | 67.65 | 65.29 | 48.84 |
| | P23 | 48.03 | 74.36 | 77.93 | 77.82 | 84.20 | 72.26 | 70.45 | 67.93 | 65.31 | 48.21 |
| | P24 | 48.19 | 74.22 | 77.43 | 77.31 | 84.46 | 72.88 | 70.16 | 67.39 | 65.84 | 48.16 |
| P3 | P31 | 50.02 | 78.23 | 82.56 | 82.45 | 89.65 | 77.45 | 75.49 | 72.39 | 70.24 | 49.43 |
| | P32 | 50.45 | 78.13 | 82.43 | 82.45 | 89.23 | 77.23 | 75.18 | 72.34 | 70.73 | 49.27 |
| | P33 | 50.13 | 78.09 | 82.73 | 82.65 | 89.45 | 77.15 | 75.79 | 72.16 | 70.29 | 49.95 |
| | P34 | 50.17 | 78.61 | 82.06 | 82.33 | 89.12 | 77.72 | 75.46 | 72.45 | 70.44 | 49.12 |
| | P35 | 54.26 | 83.21 | 87.56 | 87.45 | 94.56 | 82.26 | 80.45 | 77.48 | 75.48 | 54.12 |
| P4 | P41 | 49.13 | 77.15 | 81.12 | 81.32 | 88.59 | 76.49 | 74.45 | 71.49 | 69.26 | 48.06 |
| | P42 | 49.24 | 77.88 | 81.93 | 81.83 | 88.86 | 76.49 | 74.46 | 71.22 | 69.45 | 48.56 |
| | P43 | 49.58 | 77.71 | 81.62 | 81.46 | 88.45 | 76.82 | 74.89 | 71.67 | 69.48 | 48.89 |
| | P44 | 49.48 | 77.14 | 81.42 | 81.49 | 88.23 | 76.41 | 74.16 | 71.74 | 69.46 | 48.56 |
| | P45 | 54.12 | 82.15 | 86.65 | 86.45 | 93.87 | 81.45 | 79.36 | 76.64 | 74.44 | 53.26 |

Table 4 — SPL for the CSCC_10

| Planes | | 32.5 | 65 | 125 | 250 | 500 | 1000 | 2000 | 4000 | 8000 | 16000 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Frequency (Hz) | | | | | | | | | |
| | | SPL (dB) | | | | | | | | | |
| P1 | P11 | 47.84 | 72.32 | 75.48 | 75.08 | 82.26 | 70.40 | 68.16 | 65.54 | 63.45 | 46.85 |
| | P12 | 47.98 | 72.21 | 75.12 | 75.41 | 82.71 | 70.45 | 68.47 | 65.79 | 63.69 | 46.63 |
| | P13 | 47.35 | 72.72 | 75.16 | 75.93 | 82.86 | 70.12 | 68.81 | 65.60 | 63.32 | 46.65 |
| | P14 | 47.78 | 72.73 | 75.45 | 75.30 | 82.94 | 70.18 | 68.60 | 65.02 | 63.38 | 46.26 |
| P2 | P21 | 46.03 | 72.39 | 75.78 | 75.66 | 82.26 | 70.21 | 68.46 | 65.41 | 63.36 | 46.19 |
| | P22 | 46.77 | 72.89 | 75.59 | 75.54 | 82.59 | 70.45 | 68.18 | 65.71 | 63.78 | 46.95 |
| | P23 | 46.29 | 72.19 | 75.94 | 75.92 | 82.16 | 70.74 | 68.96 | 65.62 | 63.49 | 46.85 |
| | P24 | 46.58 | 72.45 | 75.06 | 75.86 | 82.46 | 70.49 | 68.49 | 65.41 | 63.44 | 46.44 |
| P3 | P31 | 48.89 | 77.75 | 80.26 | 80.56 | 87.45 | 75.28 | 73.88 | 70.41 | 68.42 | 48.89 |
| | P32 | 48.75 | 77.08 | 80.56 | 80.97 | 87.89 | 75.40 | 73.11 | 70.22 | 68.56 | 48.25 |
| | P33 | 48.21 | 77.65 | 80.13 | 80.83 | 87.16 | 75.37 | 73.14 | 70.82 | 68.68 | 48.15 |
| | P34 | 48.16 | 77.52 | 80.03 | 80.38 | 87.56 | 75.46 | 73.93 | 70.15 | 68.86 | 48.97 |
| | P35 | 53.21 | 82.03 | 85.23 | 85.29 | 90.31 | 80.45 | 78.49 | 75.46 | 73.12 | 53.36 |
| P4 | P41 | 47.12 | 76.32 | 79.68 | 79.85 | 86.45 | 74.78 | 72.46 | 69.45 | 67.15 | 47.25 |
| | P42 | 47.47 | 76.88 | 79.09 | 79.46 | 86.68 | 74.88 | 72.58 | 69.67 | 67.10 | 47.65 |
| | P43 | 47.44 | 76.91 | 79.45 | 79.63 | 86.52 | 74.38 | 72.49 | 69.73 | 67.49 | 47.47 |
| | P44 | 47.49 | 76.50 | 79.22 | 79.56 | 86.11 | 74.88 | 72.88 | 69.45 | 67.88 | 47.23 |
| | P45 | 52.45 | 81.48 | 84.56 | 84.23 | 91.26 | 79.45 | 77.49 | 74.16 | 72.28 | 52.20 |

CSCC_5, CSCC_10, CSCC_15, and CSCC_20) at plane 1. The results showed that the value of SAC increased with the increasing percentage of CS in the composite. The increase in SAC was because of the absorption of sound waves within the materials. The SAC was low in the 32.5-500 Hz frequency range, i.e., 0.03-0.18. On the other hand, the SAC was maximum in the frequency range of 1-4 kHz, and the value was between 0.14-0.33. Further more, the SAC again decreased in the 8-16 kHz frequency range, and the value was between 0.04-0.21. Overall, it was observed from the results that the value of SAC was maximum in the mid-frequency range (1-4 kHz), and the CSCC_20 tends to absorb more sound than their counterparts. The porous structure of CS promotes the size and volume of the air void fraction within the composites. Thus, it causes more sound energy loss and hence more sound absorption. Additionally, the

Table 5 — PL for the CSCC_15

| Planes | | 32.5 | 65 | 125 | 250 | 500 | 1000 | 2000 | 4000 | 8000 | 16000 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Frequency (Hz) | | | | | | | | | |
| | | SPL (dB) | | | | | | | | | |
| P1 | P11 | 46.89 | 70.61 | 73.36 | 73.21 | 80.56 | 68.33 | 66.45 | 63.36 | 61.85 | 45.26 |
| | P12 | 46.65 | 70.08 | 73.38 | 73.65 | 80.85 | 68.61 | 66.05 | 63.21 | 61.66 | 45.58 |
| | P13 | 46.12 | 70.77 | 73.65 | 73.54 | 80.53 | 68.16 | 66.39 | 63.82 | 61.78 | 45.52 |
| | P14 | 46.89 | 70.61 | 73.12 | 73.89 | 80.03 | 68.58 | 66.15 | 63.68 | 61.65 | 45.12 |
| P2 | P21 | 45.38 | 70.13 | 73.72 | 73.93 | 80.16 | 68.03 | 66.63 | 63.45 | 61.12 | 45.44 |
| | P22 | 45.78 | 70.74 | 73.95 | 73.26 | 80.34 | 68.46 | 66.45 | 63.49 | 61.54 | 45.63 |
| | P23 | 45.16 | 70.59 | 73.67 | 73.45 | 80.89 | 68.66 | 66.78 | 63.16 | 61.48 | 45.55 |
| | P24 | 45.09 | 70.15 | 73.04 | 73.89 | 80.03 | 68.42 | 66.12 | 63.48 | 61.44 | 45.13 |
| P3 | P31 | 47.59 | 75.40 | 78.89 | 78.59 | 85.46 | 73.15 | 71.45 | 68.49 | 66.65 | 47.85 |
| | P32 | 47.49 | 75.78 | 78.52 | 78.26 | 85.49 | 73.43 | 71.56 | 68.28 | 66.45 | 47.73 |
| | P33 | 47.68 | 75.65 | 78.27 | 78.46 | 85.78 | 73.49 | 71.89 | 68.92 | 66.39 | 47.86 |
| | P34 | 47.12 | 75.24 | 78.47 | 78.39 | 85.26 | 73.78 | 71.88 | 68.44 | 66.66 | 47.15 |
| | P35 | 52.65 | 80.85 | 83.06 | 83.15 | 90.68 | 78.49 | 76.66 | 73.16 | 71.43 | 52.21 |
| P4 | P41 | 46.95 | 74.28 | 77.75 | 77.80 | 84.12 | 72.74 | 70.14 | 67.24 | 65.52 | 46.23 |
| | P42 | 46.62 | 74.34 | 77.61 | 77.45 | 84.51 | 72.46 | 70.18 | 67.49 | 65.23 | 46.83 |
| | P43 | 46.58 | 74.65 | 77.20 | 77.10 | 84.55 | 72.57 | 70.97 | 67.33 | 65.48 | 46.63 |
| | P44 | 46.53 | 74.31 | 77.12 | 77.46 | 84.50 | 72.13 | 70.77 | 67.50 | 65.85 | 46.59 |
| | P45 | 51.55 | 79.54 | 82.26 | 82.46 | 89.67 | 77.49 | 75.58 | 72.44 | 70.85 | 51.64 |

Table 6 — SPL for the CSCC_20

| Planes | | 32.5 | 65 | 125 | 250 | 500 | 1000 | 2000 | 4000 | 8000 | 16000 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Frequency (Hz) | | | | | | | | | |
| | | SPL (dB) | | | | | | | | | |
| P1 | P11 | 45.28 | 68.13 | 71.26 | 71.26 | 78.25 | 65.34 | 63.83 | 60.37 | 58.85 | 44.25 |
| | P12 | 45.75 | 68.65 | 71.02 | 71.49 | 78.43 | 65.45 | 63.12 | 60.42 | 58.49 | 44.63 |
| | P13 | 45.59 | 68.63 | 71.88 | 71.46 | 78.98 | 65.35 | 63.43 | 60.85 | 58.79 | 44.20 |
| | P14 | 45.46 | 68.25 | 71.98 | 71.49 | 78.46 | 65.41 | 63.74 | 60.00 | 58.96 | 44.44 |
| P2 | P21 | 44.65 | 68.03 | 71.38 | 71.10 | 78.23 | 65.42 | 63.76 | 60.64 | 58.55 | 44.88 |
| | P22 | 44.20 | 68.00 | 71.46 | 71.23 | 78.54 | 65.78 | 63.67 | 60.32 | 58.48 | 44.23 |
| | P23 | 44.41 | 68.68 | 71.62 | 71.68 | 78.12 | 65.86 | 63.12 | 60.53 | 58.26 | 44.95 |
| | P24 | 44.18 | 68.49 | 71.49 | 71.46 | 78.74 | 65.72 | 63.49 | 60.94 | 58.11 | 44.87 |
| P3 | P31 | 46.32 | 73.26 | 76.59 | 76.45 | 83.16 | 70.32 | 68.45 | 65.14 | 63.15 | 46.65 |
| | P32 | 46.71 | 73.01 | 76.58 | 76.25 | 83.45 | 70.15 | 68.59 | 65.18 | 63.76 | 46.64 |
| | P33 | 46.76 | 73.72 | 76.12 | 76.42 | 83.26 | 70.66 | 68.62 | 65.33 | 63.44 | 46.75 |
| | P34 | 46.07 | 73.23 | 76.21 | 76.14 | 83.88 | 70.27 | 68.82 | 65.47 | 63.63 | 46.21 |
| | P35 | 51.68 | 78.46 | 81.56 | 81.26 | 88.46 | 75.49 | 73.45 | 70.15 | 68.45 | 51.14 |
| P4 | P41 | 45.91 | 72.45 | 75.59 | 75.65 | 82.26 | 69.45 | 67.45 | 64.85 | 62.24 | 45.52 |
| | P42 | 45.85 | 72.61 | 75.19 | 75.49 | 82.29 | 69.67 | 67.40 | 64.25 | 62.15 | 45.51 |
| | P43 | 45.46 | 72.89 | 75.02 | 75.23 | 82.03 | 69.92 | 67.33 | 64.44 | 62.49 | 45.13 |
| | P44 | 45.16 | 72.14 | 75.48 | 75.14 | 82.21 | 69.86 | 67.69 | 64.64 | 62.32 | 45.16 |
| | P45 | 50.29 | 77.59 | 80.44 | 80.30 | 87.49 | 74.13 | 72.87 | 69.26 | 67.77 | 50.63 |

value of SAC was minimum for the PCC because aggregates were non-porous due to the reduced size and volume of the air void fraction within the composite. The value of SAC for the CSCC_20 was maximum (0.12-0.33), and the value of SAC for the PCC was minimum (0.03-0.17) in the frequency range of 32.5 Hz-16 kHz. The comparison of SAC at plane 1 with respect to other planes was given in Table 7.

### 3.2 Variation in SAC at Plane 2

The variation in SAC at plane 2 was presented in Fig. 3(a-d). Similar to plane 1, the value of SAC was maximum in the frequency range of 1-4 kHz. Figure. 3(a-d) showed that in the frequency range 32.5-500 Hz, the SAC was low, i.e., 0.02-0.17, but in the frequency range of 1-4 kHz, the SAC was maximum, i.e., 0.12-0.32, and in the frequency range

Table 7 — Maximum value of SAC of materials at different planes in 3.5 mm thick glass box

| Frequency | Plane | SAC (Maximum) | | | | |
|---|---|---|---|---|---|---|
| | | PCC | CSCC_5 | CSCC_10 | CSCC_15 | CSCC_20 |
| 32.5-500Hz | Plane 1 | 0.07 | 0.09 | 0.14 | 0.16 | 0.18 |
| | Plane 2 | 0.07 | 0.08 | 0.13 | 0.15 | 0.17 |
| | Plane 3 | 0.08 | 0.08 | 0.12 | 0.13 | 0.16 |
| | Plane 4 | 0.10 | 0.08 | 0.12 | 0.14 | 0.15 |
| 1-4 kHz | Plane 1 | 0.17 | 0.24 | 0.27 | 0.29 | 0.33 |
| | Plane 2 | 0.17 | 0.22 | 0.26 | 0.28 | 0.32 |
| | Plane 3 | 0.18 | 0.24 | 0.26 | 0.28 | 0.32 |
| | Plane 4 | 0.17 | 0.23 | 0.25 | 0.27 | 0.31 |
| 8-16 kHz | Plane 1 | 0.06 | 0.10 | 0.13 | 0.16 | 0.21 |
| | Plane 2 | 0.08 | 0.10 | 0.13 | 0.17 | 0.21 |
| | Plane 3 | 0.10 | 0.12 | 0.15 | 018 | 0.21 |
| | Plane 4 | 0.06 | 0.09 | 0.12 | 0.14 | 0.19 |

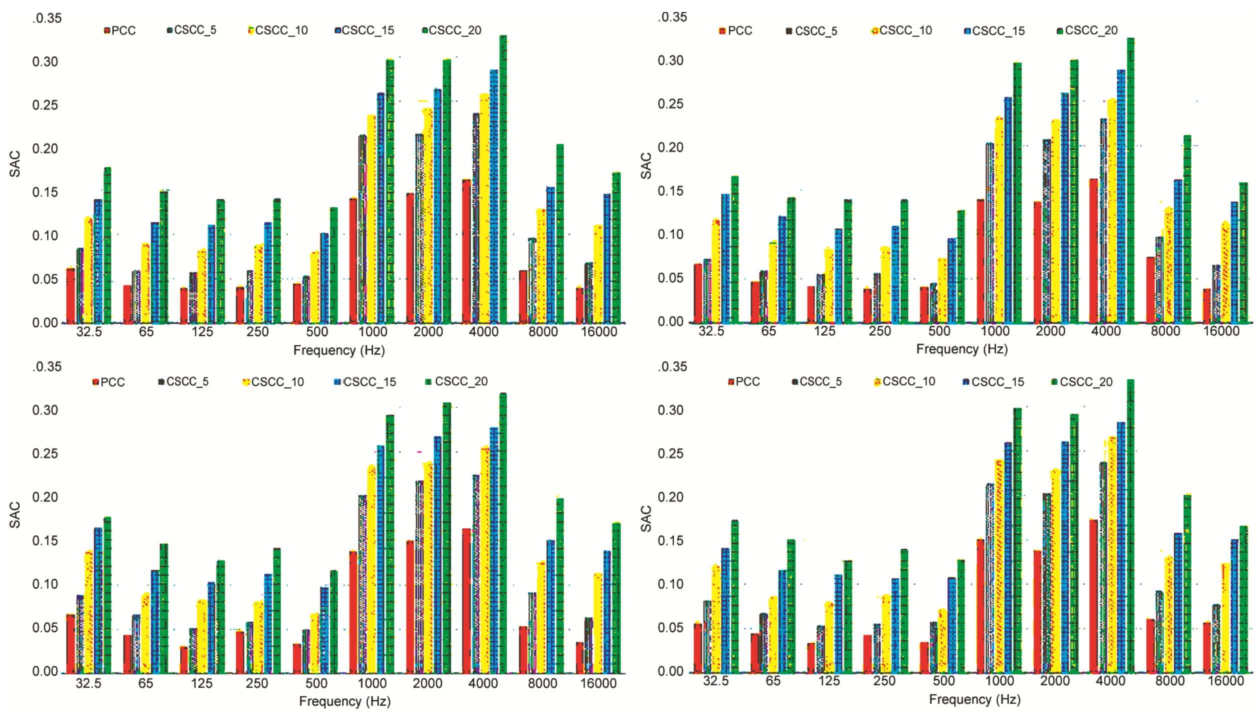


Fig. 2 — SAC at plane 1 (a) P11, (b) P12, (c) P13, and (d) P14.

of 8-16 kHz, the SAC was again decreasing and the value was between 0.03-0.21. The CSCC_20 revealed the maximum SAC compared to other samples, where as PCC discovered the minimum value of SAC. The SAC of the CSCC_20 was in the range of 0.11-0.32, and the SAC of the PCC was in the range of 0.02-0.17 for the frequency range of 32.5 Hz-16 kHz. The comparison of SAC at plane 2 with respect to other planes was given in Table 7.

### 3.3 Variation in SAC at Plane 3

The SAC for PCC, CSCC_5, CSCC_10, CSCC_15 and CSCC_20 at plane 3 was shown in Fig. 4(a-e). In plane 3, there was a hole on the top surface of the glass box. The SPL and SAC were also measured above the centre of the hole, which is named P35. It was observed that there was a significant variation in the values of SPL at P35. It was due to the direct encounter of sound with a sound level meter. The SAC was low, i.e., 0.01-0.16 in the frequency range of 32.5 Hz-500 Hz. In contrast, the SAC was maximum in the frequency range of 1-4 kHz, and the value was between 0.10-0.32. Additionally, the SAC was again decreasing, and the value was between 0.04-0.21 in the frequency range of 8-16 kHz. Similar to the above planes, the SAC was maximum for the

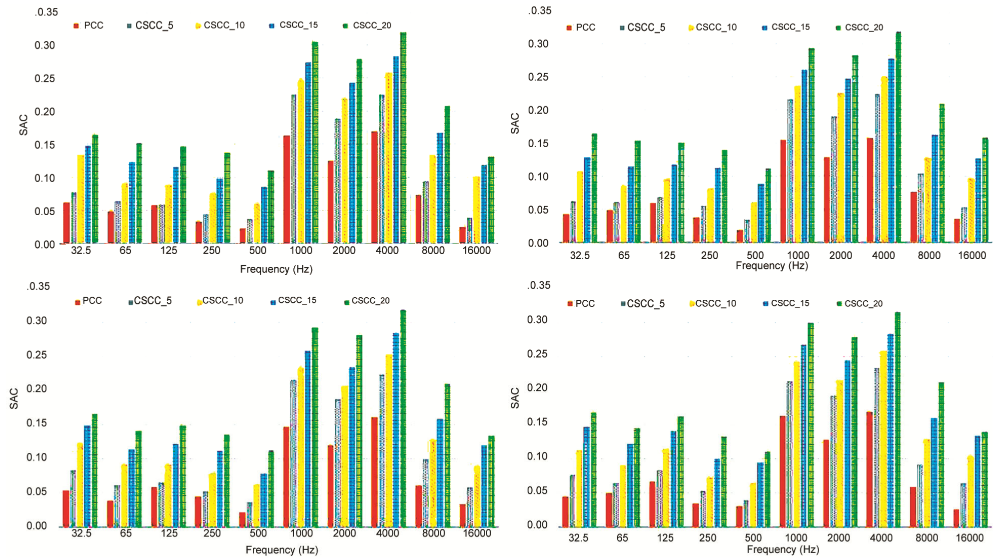


Fig. 3 — SAC at plane 2 (a) P21, (b) P22, (c) P23, and (d) P24.

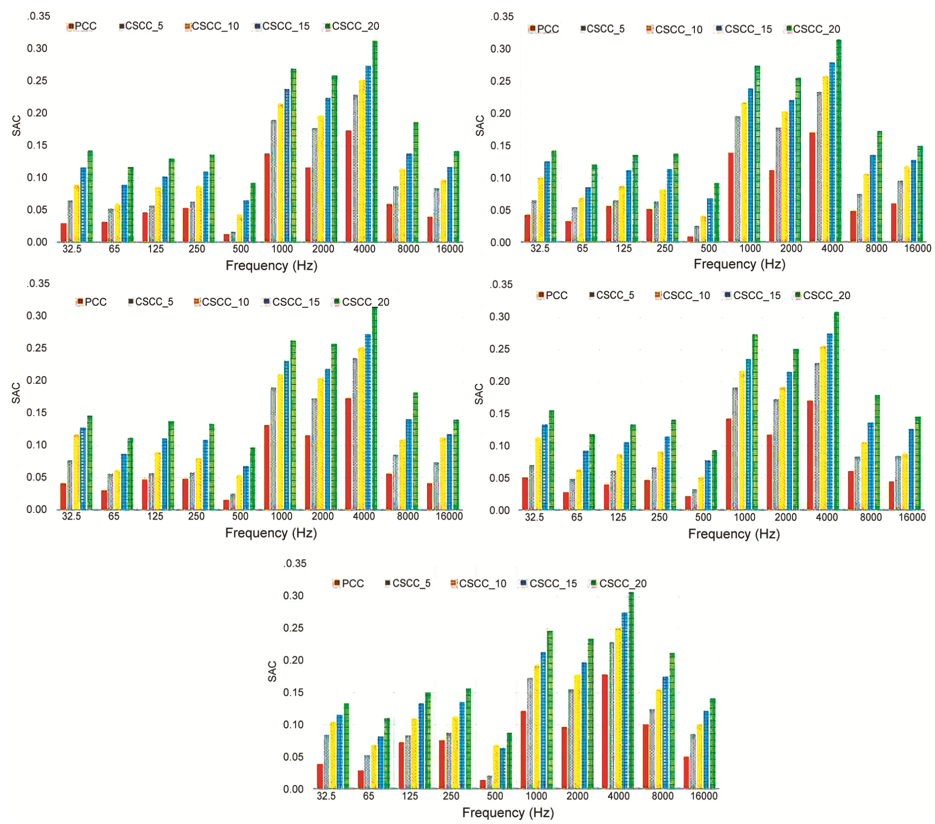


Fig. 4 — SAC at plane 3 (a) P31, (b) P32, (c) P33, (d) P34, and (e) P35.

CSCC_20 and minimum for the PCC. The value of SAC at plane 3 for the CSCC_20 was in the range of 0.09-0.32, and the value of SAC for the PCC was in the range of 0.01-0.18 in the frequency range of 32.5 Hz-16 kHz. The comparison of SAC at plane 3 with respect to other planes was given in Table 7.

### 3.4 Variation in SAC at Plane 4

Figure. 5(a-e) showed the values of SAC in plane 4. Similar to plane 3, plane 4 also positioned a point P45, and the values of SPL and SAC were also measured at that point. The SPL values at P45 were less than P35. It was because of the sound interaction

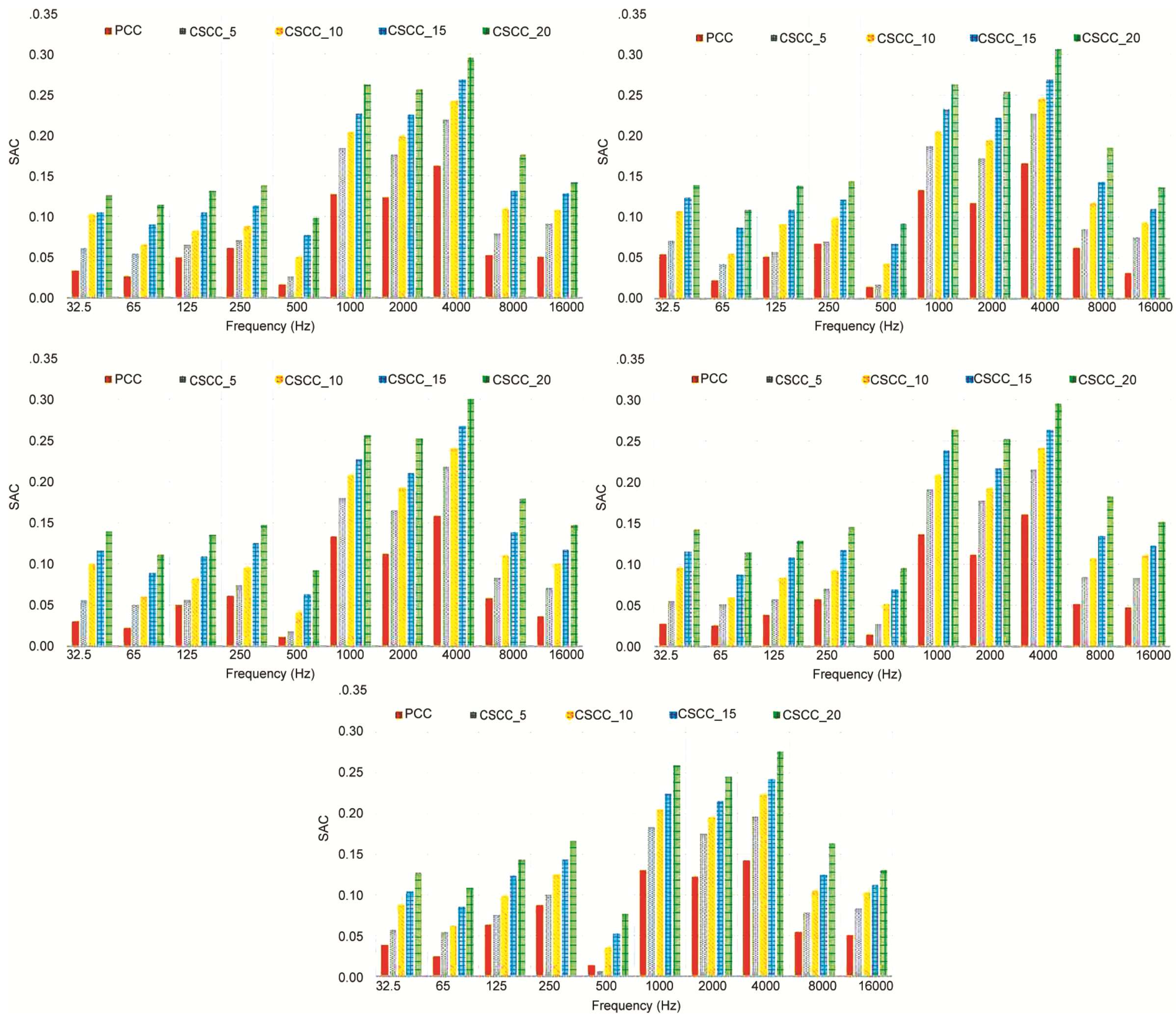


Fig. 5 — SAC at plane 4 (a) P41, (b) P42, (c) P43, (d) P44, and (e) P45.

with the atmospheric particles and hence, loss the energy. The SAC in the frequency range 32.5-500 Hzwas low, i.e., 0.01-0.17.On the other hand, the SAC was maximum in the frequency range of 1-4 kHz, and the value was between 0.11-0.31. Moreover, in the frequency range of 8-16 kHz, the SAC was again decreased, and the value ranged between 0.03-0.19. Similar to the above planes, the value of SAC was maximum for the CSCC_20 (0.08-0.31) and the minimum for the PCC (0.01-0.17). The comparison of SAC at plane 4 with respect to all other planes was given in Table 7.

Due to the non-linear behaviour of the sound-absorbing materials, the values of SAC were different in all frequency regions. The sound was reflected and refracted as it entered the concrete composite, and due to the low energy elastic collision, a small amount of sound energy was converted into heat. Therefore, the concrete composite exhibited low absorption coefficient during low frequency range. Alternatively, in medium and high frequency regions, there was more energy loss in the form of heat due to inelastic collisions. Moreover, at high frequencies, due to the coincidence dip phenomenon and in-phase relation between incidence and reflected waves, SAC[29] was decreased by a slight amount. The high wavelength sound comprised low frequencies and hence low energy. The sound waves reflected, refracted, and lost energy after colliding with the material. There was less collision and less loss of sound energy in the low frequency region. For the material with small pores or inclusions (in the case of concrete composite), there could be a difficulty for sound waves to enter into the material, which resulted in low absorption. Further more, at low frequency regions, the thickness and denser structure of the material played an important

Table 8 — Maximum value of SAC of different reinforced concrete composites

| S. No. | Type of concrete composite | Frequency Range | Maximum SAC | Ref. |
|---|---|---|---|---|
| 1. | Hemp concrete | 500-2000 Hz | 0.44-0.49 | 24 |
| 2. | Concrete with bottom ash | 1000 Hz | 0.28 | 25 |
| 3. | Glass-based concrete | 250-3150 Hz | 0.2-0.37 | 26 |
| 4. | Normal concrete | 3000-5500 Hz | 0.05-0.1 | 26 |
| 5. | Coconut fiber concrete | 1250-3200 Hz | 0.42-0.80 | 26 |
| 6. | Coconut shell concrete | 1000-4000 Hz | 0.2-0.33 | Current work |

role and exhibited a direct relationship with frequency. Because of the above reasons, all types of samples displayed decreasing trend in sound pressure level in the 500 - 1000 Hz frequency range. Also, the comparison was made with the maximum SAC of different reinforced concrete composites and CSCC. It was concluded that the SAC was maximum within the frequency range 1-4 kHz, which was consistent with the data given in Table 8.

To determine fairly accurate SPL, sufficient point density, and repeatability of the measurement, the glass cube box of 5 mm and 8 mm were also used. The maximum SAC was recorded for the CSCC_20 and the minimum for the PCC in a 5 mm thick glass box. The values of SAC for the CSCC_20 in a 5 mm glass box were in the range of 0.13–0.32 at plane 1, 0.13–0.31 at plane 2, 0.11–0.29 at plane 3, and 0.11–0.29 at plane 4. In the PCC, the values of SAC were in the range of 0.01–0.20 for plane 1, 0.01–0.20 for plane 2, 0.01–0.19 for plane 3, and 0.01–0.18 for plane 4. Similarly, the values of SAC were maximum for the CSCC_20 and minimum for the PCC in an 8 mm glass box. The values of SAC for the CSCC_20 in 8 mm at plane 1, 2, 3, and 4 were in the range of 0.10–0.36, 0.09–0.36, 0.08–0.33, and 0.08–0.32, respectively. In addition, the values of SAC for the PCC at plane 1were 0.01–0.25, plane 2 were 0.01–0.25, plane 3 were 0.01–0.22, and plane 4 were 0.01–0.22. Based on the above findings, it was concluded that the partial substitution of coarse aggregates of CS in cement concrete increased the sound absorption in principle. The interaction of sound with the CS in concrete caused sound absorption due to the porous nature of CS. The microstructural studies[27] showed the different microstructural features present in CS. At the coarsest level, the hollow elliptical channels were found running through the densest part of CS. At a finer scale, these channels were found to be in the shape of concentric rings connected in a ladder structure along the length. At a still smaller scale, this channel was revealed as a network of highly connected channels. Thus, when a sound was passed through CS, the friction between the microstructural features of CS and sound led to sound absorption. Additionally, the viscous damping of sound when it passed through porous material caused the absorption of sound energy and conversion of it into heat. Effectively, sound absorption occurred when CS of the same size replaced the coarse aggregates.

## 4 Conclusions

Waste CS has been producing a dumping problem and affects the environment. The utilization of CS in concrete manufacturing could help the dumping of bio-waste. This work has investigated the acoustic behaviour of CS reinforced concrete composite. The results have indicated that these CS reinforced composite have absorbed a relatively high sound compared to plane conventional concrete composite. Furthermore, the SPL has decreased with the increased percentage of CS in composite, and hence it has increased the SAC. The CSCC samples have SAC (0.07-0.18) in low frequency range and have displayed decreasing trend in SPL in the 500-1000 Hz frequency range due to the non-linear behaviour of the sound absorbing materials. There has been more energy loss in the form of heat due to the inelastic collisions, and hence high SAC has been found (0.17-0.33) in the medium frequency range. Further more, at high frequencies, SAC has decreased by a slight amount (0.06-0.21) due to the coincidence dip phenomenon and the in-phase relation between incidence and reflected waves.

## Acknowledgment

The first and second authors were thankful to the Ministry of Human Resource and Development (MHRD), Now Ministry of Education (MoE), Government of India, for giving Ph.D. and PG fellowship, respectively.

## References

1 Kanojia A & Jain S K, *Constr Build Mater*, 140 (2017) 150.
2 Gambhir M L, *Concrete Technology* (Tata McGraw-Hill Education, New Delhi), 2017.

3 Ranjitham M, Mohanraj S, Ajithpandi K, Akileswaran S & Deepika Sree S K, *AIP Conf Proc*, 2128 (2019) 1.

4 Soni N & Shukla D K, *Indian J Eng Mater Sci*, 27 (2021) 699.

5 Sharma R & Bansal P P, *J Clean Prod*, 112 (2016) 473.

6 Jibrael M A & Peter F, *J Ecosyst Ecography*, 6 (2016) 1.

7 Tutikian B F, Nunes M F O, Leal L C & Marquetto L, *Build Acoust*, 19 (2012) 75.

8 Fraile-Garcia E, Ferreiro-Cabello J, Defez B & Fajanes G P, *Materials*, 9 (2016) 962.

9 Holmes N, Browne A & Montague C, *Constr Build Mater*, 73 (2014) 195.

10 Olofinnade O M, Ede A N, Ndambuki J M, Ngene B U, Akinwumi I I & Ofuyatan O, *Cogent Eng*, 5 (2018) 1.

11 Ramli M, Abas N & Othuman Mydin M A, *MATEC Web Conf*, 17 (2014)1.

12 Kambli P S, & Mathapati S R, *IOSR J Eng*, 4 (2014) 1.

13 Kalyana Chakravarthy P R, Janani R, Ilango T & Dharani K, *IOP Conf Ser: Mater Sci Eng*, 183 (2017)1.

14 Zanariah J, Zaiton H, Nizam Y M, Khairulzan Y, Dianah M, Nadirah D & MohdHanifi O, E3S Web Conf, 34 (2018) 1.

15 Buah W K & Williams P T, *J Mater Cycles Waste Manag*, 14 (2012) 396.

16 Madakson P B, Yawas D S &Apasi A, *Int J EngTechnol*, 4 (2012) 1190.

17 www.worldatlas.com/articles/the-world-leaders-in-coconut-production.html (13 May 2020).

18 Nadir Y & Sujatha A, KSCE *J CivEng*, 22 (2018) 1920.

19 Gunasekaran K, Annadurai R & Kumar P S, *Mater Des*, 46 (2013) 157.

20 Jayaprithika A &Sekar S K, *Constr Build Mater*, 117 (2016) 244.

21 Cruz R A, Correa C R & Díaz-Ramírez G A, *J Phys: Conf Ser*, 1247 (2019) 1.

22 www.jute.com/documents/10437/0/SPC+FINAL+REPORT(+22-1-13).pdf/637e0db0-4bfc-4552-ad25-eb00df7138a5(13 June 2020).

23 Bies D A & Hansen C H, Engineering Noise Control Theory and practice (CRC Press, fourth edition, Spon Press London and New York), 2017.

24 Kinnane O, Reilly A, Grimes J, Pavia S & Walker R, *Constr Build Mater*, 122 (2016) 674.

25 Leiva C, Vilches L F, Arenas C, Delgado S, & Pereiraarenas C F, *ACI Mater J*, 109 (2012), 529.

26 Fediuk R, Amran M, Vatin N, Vasilev Y, Lesovik V, & Ozbakkaloglu T, *Materials*, 14 (2021)

27 Gludovatz B, Walsh F, Zimmermann E A, Naleway S E, Ritchie R O &Kruzic J J, *J Mech Behav Biomed Mater*, 76 (2017) 76.