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ARTICLES

INFORMATION

FOREWORD

Building acoustics is the science of controlling noise in buildings. This includes the minimization of noise transmission from one space to another and the control of the characteristics of sound within spaces themselves. Building acoustics is an important consideration in the design, operation, and construction of most buildings, and can have a significant impact on health and wellbeing, communication, and productivity. They can be particularly significant in spaces such as halls, recording studios, lecture theatres, and so on, where the quality of sound and its intelligibility are very important.

The first paper of speech source localization in St Roque church, Goa is an effort to identify the altar location that would provide optimal conditions of speech, music, singing, and silence in the mutual communication between the Presiding Priest and the congregation during any liturgical celebration in the church. The second paper aims to present the experimental analysis of the air gap thickness (AGT) effect on the sound absorption coefficient (SAC) of echo wood material. The frequency range considered for the experiment is 0.1KHz to 4KHz. Further, the behavior of echo wood SAC is classified as a function of frequency, as noise frequency control in different applications is a crucial task. The third study reports the sound insulation of coir fiber-reinforced composites at different fiber loadings and the role of the interface on transmission loss. Therefore, coir fibers were used in this study as reinforcement in the polypropylene matrix, and composites were studied for sound insulation properties. Sodium hydroxide was used for surface treatment of coir fibers to study the role of the interface on sound insulation of composites. The fourth study of acoustical characteristics is important to understand sound propagation, absorption, build up, and aural comfort in closed and open spaces. This article presents experimental investigation and analyses of the acoustical characteristics of a renovated room in the Mechanical Engineering Department of the Aligarh Muslim University (AMU). The fifth study aims to investigate the sound absorption property of fluoro-gypsum (FG) material in the low audio frequency regime by the acoustic impedance tube method. The morphological feature of fluoro-gypsum material is also studied by field emission scanning electron microscopy (FE-SEM) technique

As I conclude this overview, I express my sincere gratitude to Dr. D. K. Aswal, Director, CSIR-NPL, and President, ASI for his encouragement to bring out this special issue. I am thankful to Dr. B. Chakraborty, Chief-in-Editor of JASI for his support throughout the preparation of this issue. I also acknowledge the reviewers for their support providing valuable time to improve the quality of the papers.

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Altar speech source localization in St Roque Church, Goa

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ABSTRACT

St. Roque Church, Tollecantto, Goa originally a Chapel built-in 1883 is presently undergoing conservation procedures. As part of conservation, the altar speech source, for optimal communication during the liturgical celebration, has to be localized inside the worship space of the church. Impulse Response Tests were conducted in the church for three different altar source positions (original High Altar; Existing Altar; Proposed altar) with recordings done at ten locations. Multi-source spectral investigation of RT60, Leq and RASTI identified the presently used altar position as the acoustically correct location for the altar speech source in the church.

1. INTRODUCTION

St. Roque church, Tollecanto, Goa (São Roque Igreja' in Portuguese) built-in 1883 is a diminutive sanctuary village church of Goa, shown in Figure 1, comprising of three bays and three storeys in Rococo Neo-Roman design[1,2]. The 'Altar' in the worship space of a church is the focal point of attention[3]. At the Altar, the Presiding Priest conducts the 'Eucharist'. During the Eucharistic celebration, the Priest speaks,

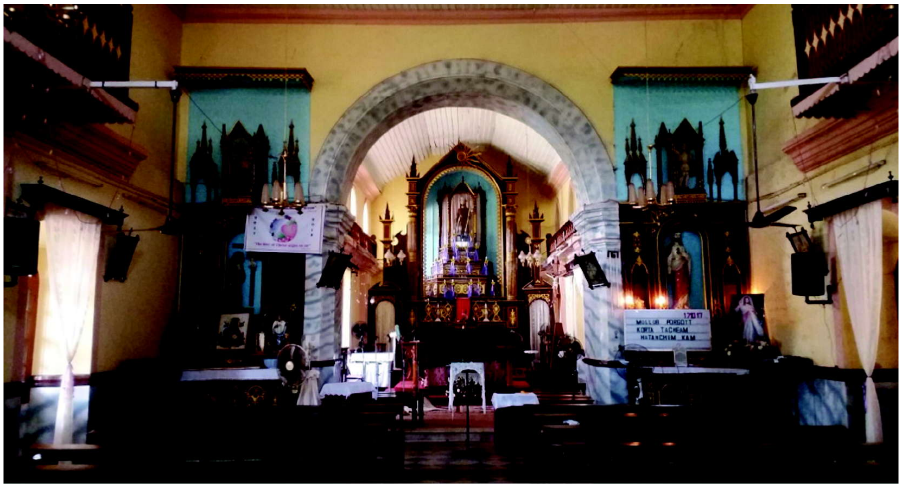

Fig. 1. The interior worship space of St. Roque church.

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chants or sings, thus requiring this location to provide optimal conditions of speech, music and singing[4-7].

The original Altar location (called the 'High Altar') was part of the retable facing the sanctuary of the church. The High Altar was used during the pre-Vatican era wherein the Priest would celebrate the Eucharist facing the Retable. The present altar location is situated in the middle of the sanctuary at which the Priest celebrates the 'Eucharist' facing the congregation. The third altar location was proposed in view of the church undergoing longitudinal expansion during its conservative rehabilitation. This study was an effort to identify the altar location that would provide optimal conditions od speech, music, singing and silence in the mutual communication between the Presiding Priest and the congregation during any liturgical celebration in the church. The acoustical characterization as a conservation procedure enables the heritage edifice to preserve essential aesthetics while restoring the erstwhile character-defining elements of the church[8,9].

2. METHODOLOGY

Monaural measurements of acoustical impulse response were carried out in the empty St. Roque church, in accordance with ISO 3382 set of standards[10], for three sound source positions (S1: Retable High Altar, S2: Existing Altar in Sanctuary and S3: Proposed Altar location under sanctuary arch) and for ten characteristic receiver locations. Recording locations situated inside the church are considered (S1, S2, S3 - in the sanctuary, three locations in the nave and one in the narthex) as shown in Figure 2.

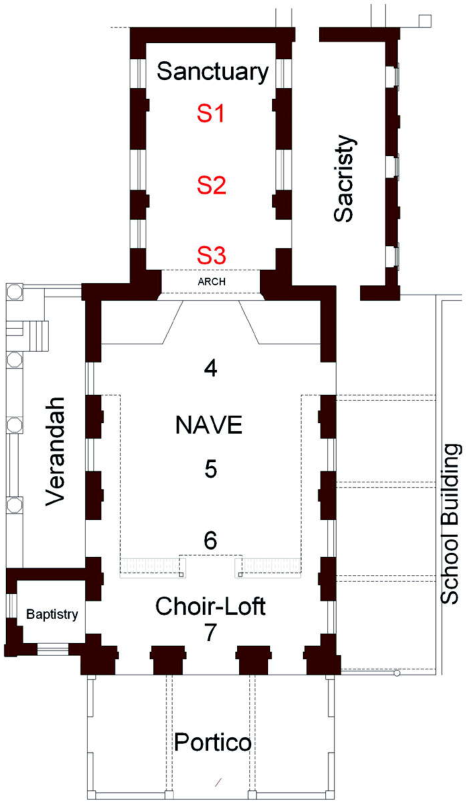

Fig. 2. Existing Floor Plan of St. Roque church with marked locations of sound sources (S1, S2, S3) and recording locations (S1, S2, S3, 4, 5, 6, 7).

The optimal location for the altar was identified from the RT60 spectral analysis of the possible sound sources, a positional variance of Loudness and Speech Intelligibility[11] and multi regression of RT60 with other monaural acoustical measures. The acoustical analysis was done using ARTA 1.9.2, Microsoft Excel 2007 and Origin 6.1.

3. RESULTS AND DISCUSSION

3.1 A multi-source positional spectral variance of RT60

The spectral variance of RT60 for S1, S2, and S3 at different recording positions in St. Roque church is shown in Figure 3, Figure 4 and Figure 5 respectively.

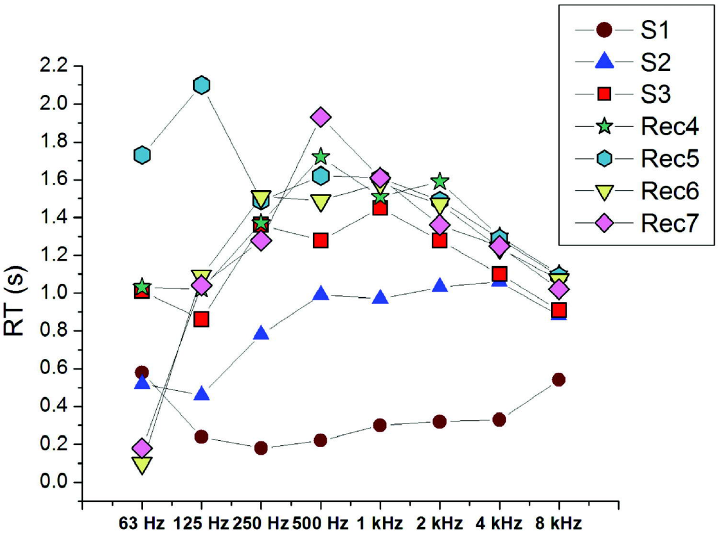

Fig. 3. Spectral variance for RT60 at Source 1 (Retable altar location) in St. Roque church.

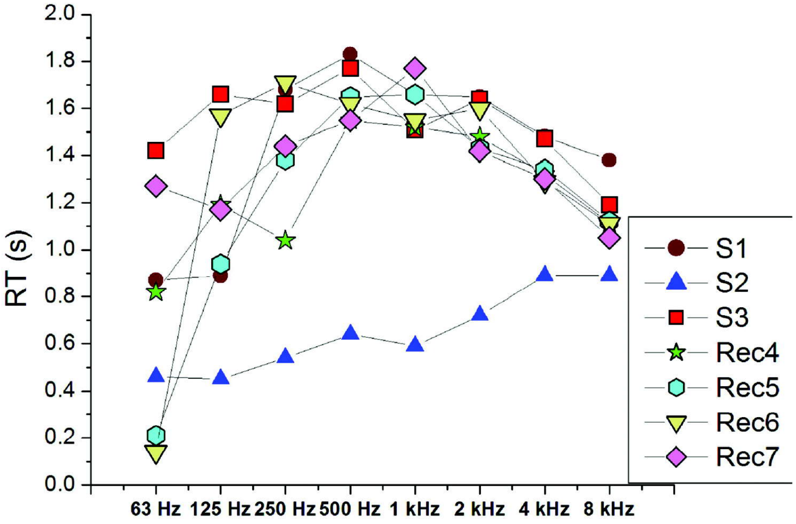

Fig. 4. Spectral variance for RT60 at Source 2 (Present altar location) in St. Roque church.

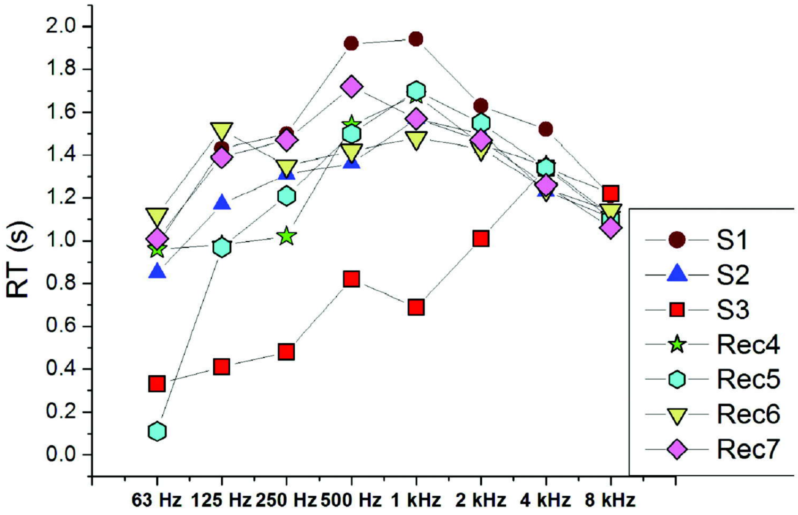

Fig. 5. Spectral variance for RT60 at Source 3 (Proposed altar location) in St. Roque church.

3.2 Multi-source positional variance of Leq and RASTI

The positional variance of Loudness (Leq) and Speech Intelligibility (RASTI) for sources S1, S2 and S3 are shown in Figure 6.

3.3 Multi-Regressions of RT60 with monaural acoustical measures

The significant ($p \leq 0.05$) multi-regressions of RT60 with other monaural acoustical measures at different source locations are shown in Table 1.

4. INTER-SOURCE ACOUSTICAL ANALYSIS

At Source 'S1' impulse, RT60 showed asymmetric higher values in the frequency bands of 63 Hz & 125 Hz (ranging from 1.7s - 2.1s) at Recording location'5' (in the middle of the nave) while averaging 1.29

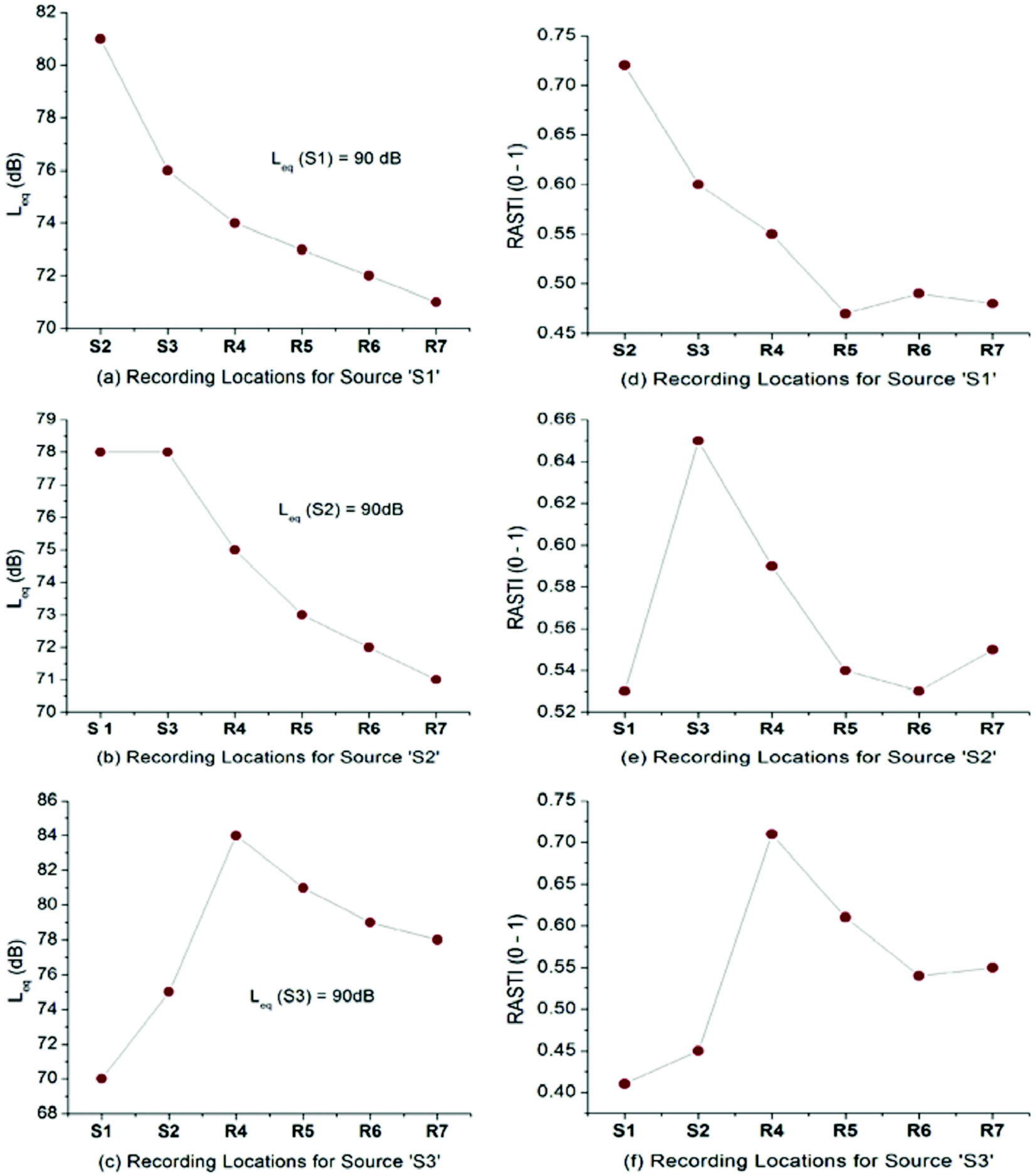

Fig. 6. Positional variance for Leq and RASTI in St. Roque church.
(a) The positional variance of Leq for Source 1
(b) Positional variance of Leq for Source 2
(c) Positional variance of Leq for Source 3
(d) Positional variance of RASTI for Source 1
(e) Positional variance of RASTI for Source 2
(f) Positional variance of RASTI for Source 3

Table 1. Significant multi regression of RT 60 with monaural acoustical measures

Rec. Loc.	Pediction Equation at Source 'S1'	R^2	p-value
S1	RT60 = 2.99 - 0.39EDT + 0.05C80 - 0.04D50 + 0.001TS	0.96	0.004
S2	RT60 = 1.18 + 0.70EDT - 0.02C80 - 0.004D50 + 0.009TS	0.97	0.01
S3	RT60 = -2.30 + 1.33EDT+ 0.11C80 + 0.01D50 + 0.01TS	0.94	0.03
Rec4	RT60 = 4.45 + 0.78EDT+ 0.18C80 - 0.06D50 - 0.015TS	0.98	0.007
Rec6	RT60 = -0.76 + 2.13EDT + 0.29C80 - 0.03D50 + 0.001TS	0.98	0.006
Rec7	RT60 = -0.12 + 1.42EDT + 0.07C80 - 0.01D50 - 0.002TS	0.998	0.02

Rec. Loc.	Pediction Equation at Source 'S2'	R^2	p-value
S2	RT60 = 6.9 - 0.11EDT + 0.02C80 - 0.06D50 - 0.03TS	0.9	0.03
S1	RT60 = -0.28 + 0.65EDT - 0.06C80 + 0.02D50 - 0.003TS	0.9	0.03
Rec4	RT60 = -0.49 + 0.56EDT - 0.10C80 + 0.02D50 + 0.004TS	0.98	0.001
Rec5	RT60 = 1.06 + 1.04EDT - 0.04C80 - 0.01D50 - 0.005TS	0.97	0.002
Rec6	RT60 = 2.16 + 0.29EDT + 0.03C80 - 0.015D50 - 0.004TS	0.85	0.05
Rec7	RT60 = 0.54 + 0.65EDT - 0.1C80 + 0.007D50 - 0.002TS	0.93	0.01

Rec. Loc.	Pediction Equation at Source 'S3'	R2	p-value
S1	RT60 = 0.76 + 1.11EDT - 0.04C80 + 0.0015D50 - 0.007TS	0.998	<0.0001
S2	RT60 = 0.56 + 0.56EDT - 0.04C80 + 0.01D50 - 0.002TS	0.89	0.03
Rec5	RT60 = 1.18 + 0.83EDT - 0.04C80 - 0.007D50 - 0.006TS	0.96	0.04
Rec6	RT60 = 2.23 + 0.63EDT - 0.02C80 - 0.015D50 - 0.01TS	0.86	0.05
Rec7	RT60 = 1.42 + 0.9EDT - 0.1C80 - 0.003D50 - 0.01TS	0.99	0.0006

seconds in the church. At Sources 'S2' and 'S3' impulses, RT60 showed a more uniform behavior with the space responding a little more reverberant, averaging 1.42 seconds in the church (for both the sources) Noteworthy observation is of the immediate frontal recording position 'S3' is the most reverberant (in most spectral bands) for Source 'S2' (cf. Figures 3-5).

While the impulse response at the back of the nave and in the narthex is quieter (in terms of Leq) for impulses from sources 'S1' and 'S2', the sanctuary becomes quiet for the impulse from source 'S3' (cf. Figures 6 a-c). The impulse from the existing altar location (Source 'S2') elicits comparatively better speech intelligibility (in terms of RASTI) in the nave and the sanctuary averaging 0.57 in the church (cf. Figures 6 d-e).

RT60 showed a significant ($p \leq 0.05$) positive correlation with C80 and TS and showed a significant negative correlation with EDT and D50 for source 'S1' recording at source point (S1). RT60 showed a significant positive correlation with C80 and showed a significant negative correlation with EDT, D50 and TS for source 'S2' recording at source point (S2). However, at source 'S3', RT60 could not be predicted significantly from the monaural acoustical measures recording at source point (S2) and at recording position '4' (front-nave space). RT60 did not regress significantly with the monaural acoustical measures also at source 'S1' for Recording position '5' (mid-nave space).

5. CONCLUSIONS

Looking at the cumulative spectral decay at each source and the spectral behavior and significant multi-regressions of RT60 along with the wideband values of RASTI and Leq, the source 'S2' (existing altar location) seems to provide a better acoustical climate in the church in terms of good reverberance coupled with speech intelligibility and adequate loudness. Therefore, it is recommended to retain the altar location to its existing position.

6. ACKNOWLEDGEMENTS

We acknowledge gratefully, Society of Pilar, Goa, Most Rev. Filip Neri Archbishop of Goa and Parish Priest and Fabrica of St. Roque church, for permission to pursue this research.

We are appreciative of our team: Paxton Fernando (Martha Developers), Arch Sarvesh Naik, Arch. Ketak Nachnolkar, Nixon Fernandes, Anthony Miranda, Mankam Mossang and all the experts and artisans involved in the conservation of St. Roque church.

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Analyzing sound absorption coefficient of echo wood material with different air gap thickness

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ABSTRACT

In this paper, the sound-absorbing characteristics of echo wood material for 0 Hz - 4.00 kHz frequency range with different air gap thickness (AGT) has been presented. This analytical observation helps to explore the echo wood's potential to be used as a good sound-absorbing material. The reverberation room of the acoustic and vibration metrology lab of the CSIR-National Physics Laboratory, New Delhi, India is used to measuring the SAC (Sound absorption coefficient) with two AGT's *i.e.* 20 mm and 50 mm. This experimental study is tested as per ISO 354 (2003) standard of noise absorption coefficients. The maximum SAC response of the panel is 0.62 and 0.87 at a frequency of 1.6 kHz and 0.8 kHz with AGT of 20mm and 50 mm, respectively. The statistical analysis is also done with the results of SAC to find the best curve fitting model using IBM SPSS Statistics 22. The frequency ranges selected for statistical modeling are frequency (0.1 kHz - 4 kHz), lower frequencies (0.1-0.5 kHz), medium frequencies (0.6 - 1.2 kHz) and higher frequencies (1.5 - 4 kHz). This analysis shows that the echo wood panel can be used as sound-absorbing material over different frequency ranges depending upon the frequency of source noise.

1. INTRODUCTION

Noise pollution has many adverse effects on the environment. Presently, it is a prime concern of the world. Urbanization and excess use of motorized transport systems are some of the main responsible factors for environmental noise. The environmental noise is generally described as the noise emitted from all sources except industrial workplaces[1]. Hunashal and Patil have summarized the assessment of noise pollution indices in the city of Kolhapur[2]. Many Indian cities are listed among the topmost noise polluted cities of the world[3]. The use of sound absorption material can decrease the acoustic energy of sound, which helps to reduce noise pollution. These materials are often made of a porous material like foam or specially constructed fiber-glass[4]. Echo wood is also a sound-absorbing material that can be utilized as a perforated acoustic panel. These panels are environmentally responsible and exhibit good sound absorbing characteristics. These panels are mainly used in large stadiums, cinemas, meeting rooms, office room, music hall, theater, workshops, *etc.*

The term Sound absorption coefficient (SAC) indicates the sound-absorbing ability of a material. The sound absorption characteristics of wooden and porous materials are related to their surface porosity. SAC of a material is a function of frequency[5]. The sound absorption at low frequencies is a major point of concern in noise control engineering. Air gap thickness (AGT) is another impor-tant parameter to improve the SAC of a material. AGT is the gap between the material and the backplate of a panel[6]. The introduction of an air gap at the back panel of the material improves its absorption efficiency[7]. David and Zainal have investigated the effect of AGT on the bio-based foam material's SAC. They have observed that increasing the AGT in the acoustic panel improves the low noise frequency absorption capacity of a material[8].

The aim of this paper is to present the experimental analysis of the AGT effect on the SAC of echo wood material. The frequency range considered for the experiment is 0.1 KHz to 4 KHz. Further, the behavior of echo wood SAC is classified as a function of frequency.

The paper is organized into three sections. Section 1, briefs the Introduction. Section 2, presents experimentation work in which sample preparation and method are discussed. The result and dis-cussion are compiled in Section 3. Finally, Section 4 concludes the paper.

2. EXPERIMENTATION

The Echo wood material is a good alternative to the wooden interior. It is made by species like ayous (also known as obeche or Samba) and basswood (Tilia also known as Linden). In this expe-riment, echo wood is used as a specimen.

2.1 Sample Preparation

Specimens are cut to a rectangular plate of dimensions 3.61m × 3.2m with a thickness of 10mm as shown in Figure 1. Two panels of 20 mm and 50 mm AGT's are designed using this sample and estimate the SAC to find the potential of echo wood material[9] as sound-absorbing material.

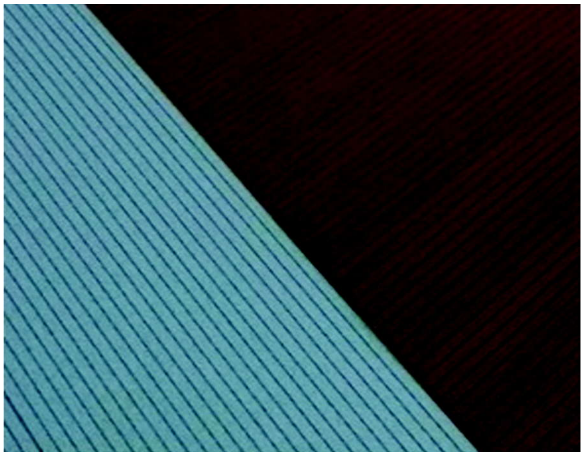

Fig. 1. Echo Wood Sample.

2.2 Method

Reverberation room method is a popular way of evaluation of sound-absorbing property of the acoustic materials[10]. It is obtained from the two measured reverberation times when a specimen is placed in a reverberation room, and when it is not placed. The reverberation time is calculated from the decay of the sound pressure level as a function of time at a certain point in the room[11]. This method has been widely used as an index for evaluating sound-absorbing efficiency of the acoustic design of a concert hall, interior materials for automobiles, construction materials and so on[12]. The experiment is performed using the

ISO 354 (2003) standard in the frequency range between 0.1 KHz and 4 KHz. The experiment is performed in the reverberation room of the Acoustics and vibration Metrology section of CSIR-National Physics Laboratory (NPL), New Delhi. The volume of the reverberation room is 260 m^3. Air gaps of 20 mm and 50mm are then introduced in the posterior in the panel to find out the effect on SAC. The Bruel and Kjaer type 2270 building analyzer is used to acquire and process the acoustic signals and the 7830 building acoustic software is employed for the computation of SAC[13]. Figure 2 shows the installed echo wood acoustic panel in the reverberation room with 20 mm and 50mm air gaps.

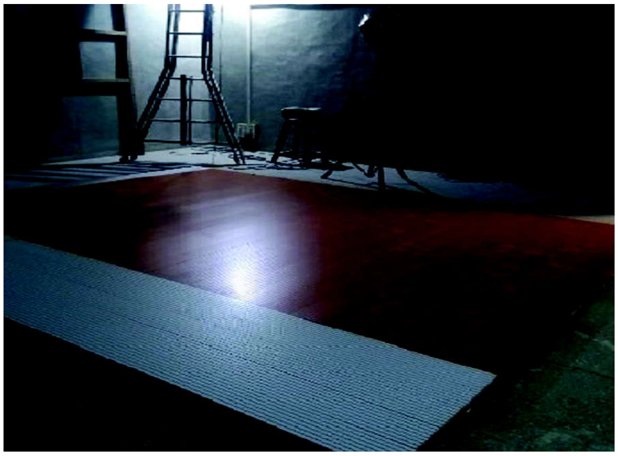

Fig. 2. Echo Wood Acoustic Panel Installed in the Reverberation room.

3. RESULTS AND DISCUSSION

3.1 Effect of AGT on SAC

Effect of SAC of echo wood material observed at the frequency range from 0:1 KHz to 4 KHz with different AGTs of 20 mm and 50 mm. SAC response over the frequency range of 0:1 KHz to 4 KHz is shown in Figure 3. From the figure, it is clear that AGT with 50 mm performs better for low-frequency ranges (0.1 KHz to 1.25 KHz). Whereas, for the high-frequency range (1.25 KHz to 2.5 KHz), the panel

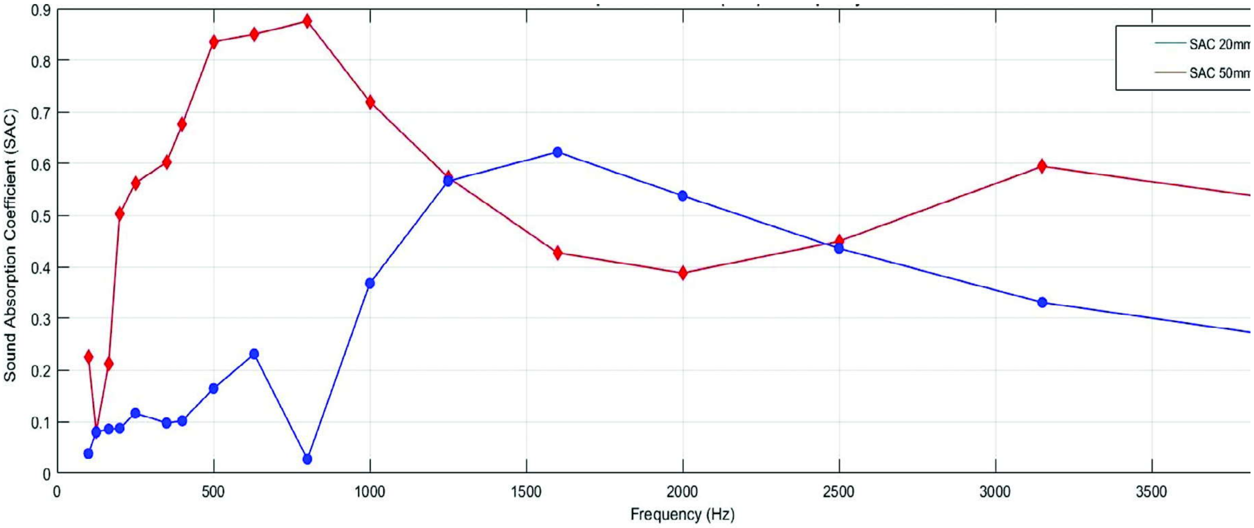

Fig. 3. SAC Response of 20 mm and 50 mm AGT.

with 20 mm AGT shown better SAC than 50 mm. The behavior of sound absorption is again changed after 2.5 KHz to 4 KHz but it cannot be taken as a reference due to insufficient data over this range. These results show the different behavior of SAC of a panel with 20 mm and 50 mm AGT w.r.t. frequency.

3.2 SAC behaviour with different frequency ranges

In this section, curve fitting analysis is examined for 20 mm and 50 mm AGT's SAC over selected frequencies. Curve fitting is the process of constructing a curve, or mathematical function from a series of data, that has the best fitting with the selected standard curves. Fitted curves can be used for data visualization to predict the values of a function where no data is available. This can be also used to summarize the relationships among two or more variables.

3.2.1 Frequency Range (0.1 KHz to 4 KHz)

SAC behaviour of panel with a 20 mm air gap for the full range of frequency is examined on several models using IBM SPSS Statistics 22. The best curve fitting model of SAC for panel with a 20 mm air gap is quadratic and with 50mm AGT, the S-curve model performs better among others. SAC curve fitting models for 20 mm AGT and 50 mm AGT is given in Table 1.

Table 1. Curve estimation of SAC of 20 mm and 50 mm AGT.

Model	Linear	Quadratic	Exponential	Inverse	Cubic	S-Curve
With 20mm AGT	0.317	0.873	0.412	--	--	--
With 50mm AGT	0.003	0.077	0.039	0.394	0.417	0.507

The curve fitting behaviour of SAC over the full frequency range of 20 mm and 50 mm AGT for several models are shown in Figure 4(a and b).

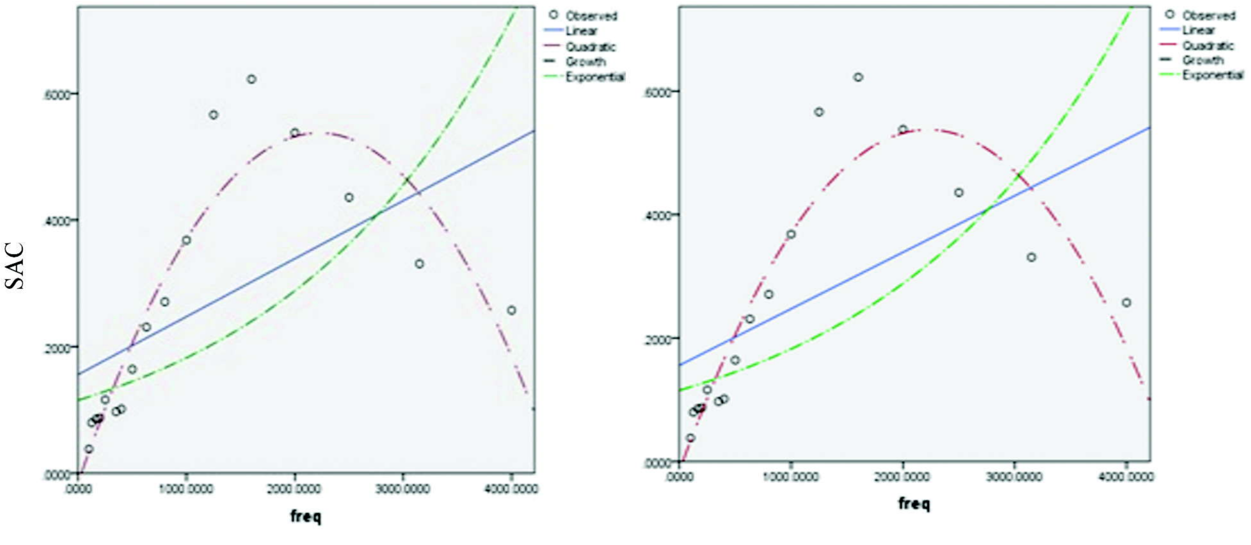

Fig. 4. SAC behaviour of 20 mm and 50 mm AGT with different models.

3.2.2 SAC Behaviour over different sets of frequency

SAC behaviour of panel with 20 mm and 50 mm AGT for a different set of frequency ranges *viz*. low frequency (<0.5 kHz), medium frequency (0.5 kHz -1.25 kHz) and High Frequency (> 1.25 kHz) is examined to linear models using IBM SPSS Statistics 22. The curve fitting value with a linear model for a different set of the frequency of 20 mm and 50 mm AGT is summarized in Table 2. The curve fitting of SAC

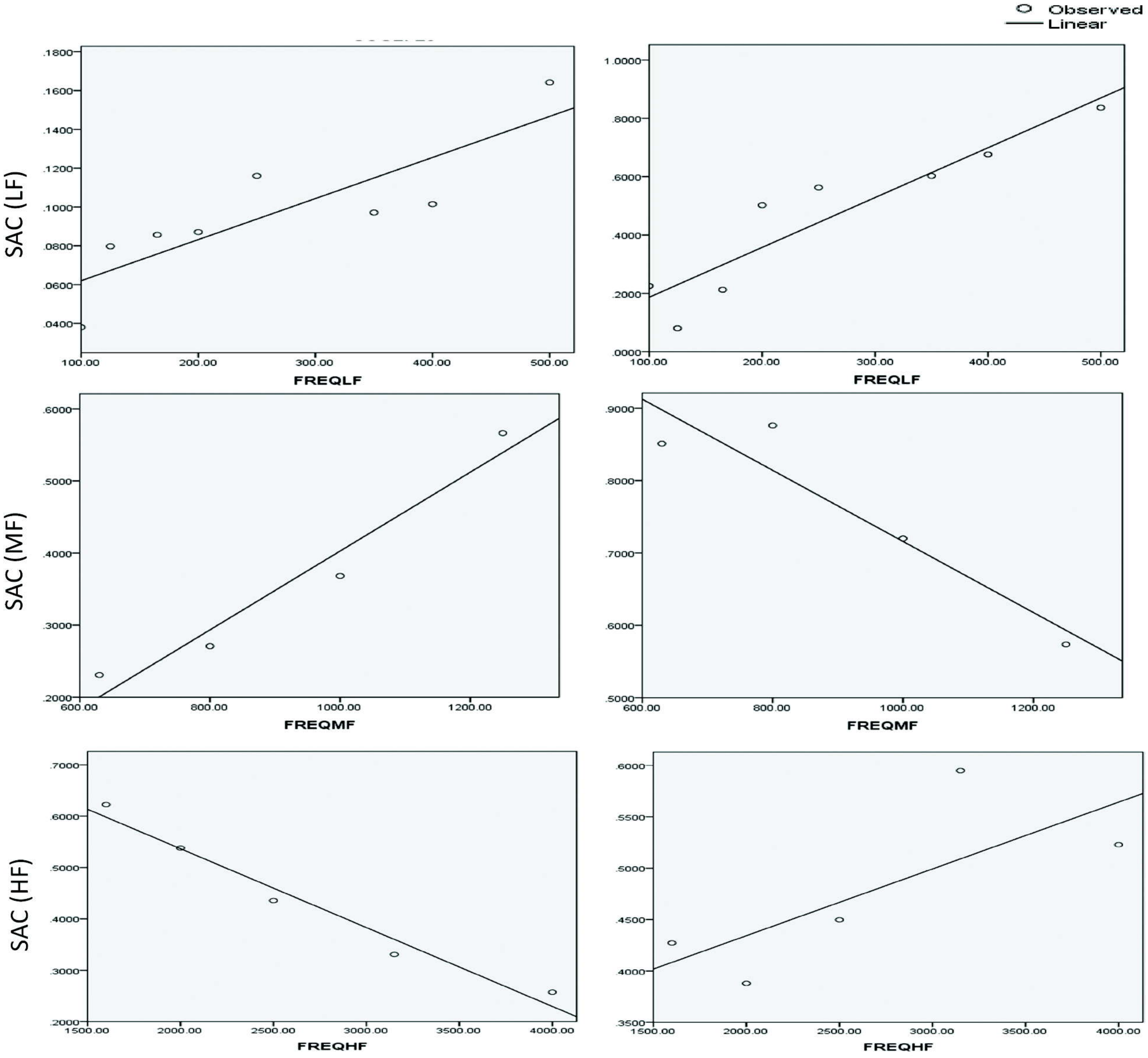

Fig. 5. (a, b, c, d, e, and f): SAC linear behaviour 20 mm and 50 mm AGT.

behaviour of 20 mm and 50 mm AGT to linear model over different sets of the frequency range is shown in Figure 5(a-f).

Table 2. Curve fitting of SAC behaviour of 20mm and 50mm AGT with Linear Model.

Model	20 mm Air Gap (LF)	50 mm Air Gap (LF)	20 mm Air Gap (MF)	50 mm Air Gap (MF)	20 mm Air Gap (HF)	50 mm Air Gap (HF)
Linear	0.715	0.859	0.950	0.889	0.968	0.562

4. CONCLUSION

Noise frequency control in different applications is a crucial task. It requires an appropriate acoustic panel for the best sound absorption effect. In this manuscript, the effect of AGT of echo wood material on SAC is investigated at a wide range of frequencies (0.1 kHz to 4 kHz). It is observed that SAC of the panel with 20 mm AGT behaves differently to panel with 50 mm AGT. SAC of a panel with 50 mm AGT performs better in low-frequency ranges whereas, SAC of a panel with 20 mm AGT performs better in higher frequency ranges. This experimental result shows that the 50 mm air gap panel is more suitable for low noise frequency and a 20 mm air gap panel is better for high noise frequency. The curve fitting of both panels SAC is investigated with different models to find the nature of SAC's. This result indicates the best curve fitting value of 20mm air gap SAC with quadratic (approx. 87%) and 50mm air gap SAC with S-curve (approx. 50%). Since both panels do not fit with the linear model so SAC response is classified over sets of frequency ranges. The result of SAC over different sets of the frequency of 20 mm and 50 mm AGT panels fits satisfactory with the linear model. Correlation between panels with 20 mm and 50 mm AGT for selected ranges of frequency is also estimated to find the relation between 20 mm and 50 mm panels SAC. Correlation analysis result indicates low matching with 20 mm and 50 mm SAC in the full range of frequency whereas high matching in the selected range of frequencies.

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Effect of fibre loading and surface treatment on sound insulation of coir fibre composites

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ABSTRACT

This study reports the sound insulation of coir fibre reinforced composites at different fibre loadings and the role of the interface on transmission loss. Sodium hydroxide was used for surface treatment of coir fibres. Polypropylene was used as matrix and composites were fabricated at 10%, 20% and 30% fibre loadings using compression moulding technique. Sound insulation of samples was determined using an impedance tube with a four-microphone arrangement. The transmission loss of alkali-treated composites was compared to that of untreated fibre composites. Effect of surface treatment of fibres and the role of the interface on sound insulation has been discussed in detail. Coir fibre composites with 30% fibre loading displayed the highest increment in transmission loss after fibre treatment.

1. INTRODUCTION

Fibre-reinforced polymer composites have been widely used in various applications such as aerospace, automobiles, sports, furniture, temporary shelters etc. for many decades. The higher specific strength and ability to develop desired properties according to the end-use gives polymer composites an advantage over traditional monolithic materials[1, 2]. However, the reinforcements in the form of fibres are usually synthetic fibres. Glass, carbon, polyester and Nylon 6 are among widely used synthetic fibres. Polymer composites produced from these fibres are mostly non-biodegradable and derived from petroleum products. Cost and availability of these fibres depend on petroleum which is a depleting natural resource. Therefore, various natural fibre has been explored by the research community as a possible reinforcement for polymer composites[3, 4]. These fibres have the advantage of availability in abundance, renewable, low density, moderate strength, less wear of machinery, biodegradability and low cost. Composites based on plant-based fibres such as jute[5, 6], hemp[7], sisal[8, 9], banana[10-12], coir[13, 14], flax[15, 16], ramie[17], bamboo[18] are widely reported. All these fibres are physically and morphologically different but have similar chemical composition. Plant fibres have the highest fraction of cellulose, and hemicellulose, lignin and other constituents in minor fraction. Polymer composites reinforced by plant-based fibres suffer from poor adhesion with the matrix that in turn, results in inferior mechanical properties[4]. Various chemical

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surface treatments such as alkali, benzoylation, silane and peroxide are reported by researchers to enhance the interface between hydrophilic fibres and hydrophobic matrices[19-21].

India is the second-largest producer of coir in the world but the use of coir in polymer composites is relatively lower than traditional applications such as ropes and mats[22]. Coir fibres have a large lumen which entraps air, which results in lower density and higher bulk as compared to other plant fibres[23]. Therefore, coir fibres were used in this study as reinforcement in polypropylene matrix and composites were studied for sound insulation properties. Sodium hydroxide was used for surface treatment of coir fibres to study the role of the interface on sound insulation of composites.

2. EXPERIMENTAL

2.1 Materials

Coir fibres were procured from Tokyo Engineering Pvt., Coimbatore, Tamil Nadu. Film produced from Reliance H110MA polypropylene chips was used for making composites. MFI of polypropylene was 11g/10 min. Sodium hydroxide in pellet form was procured from Fischer scientific.

2.2 Methods

2.2.1 *Surface treatment*

Coir fibres were cut into fibre length of 1 cm and washed with lukewarm water to remove impurities. Alkali treatment of coir fibres was carried out by immersing the fibres in sodium hydroxide solution of 5% concentration. The temperature of alkali treatment was maintained at 27°C. After 12 hours, fibres were taken out and washed thoroughly with running tap water to remove the excess of alkali. Fibres were dried overnight in a hot air oven at 60°C for 12 hours. Fibres were placed in airtight polypropylene zipper bags to avoid regaining moisture.

2.2.2 *Composite fabrication*

Fibres were hand-laid in between two layers of polypropylene films and placed in the compression moulding machine. The temperature of 167°C and pressure of 1 MPa was applied to fabricate the composite samples. The thickness of composites was maintained at 3.2 mm. Composites were cut into desired dimensions for testing in an impedance tube. Two different sizes for each set were cut into circular shapes having a diameter of 30 mm and 100 mm. 100 mm diameter samples were used for sound absorption testing at lower frequencies and 30 mm diameter samples were used for testing at higher frequencies.

3. TESTING

The samples were prepared into the required dimensions of 100 mm diameter and 30 mm in diameter. The setup was arranged with two microphone method as prescribed in standard method DIN EN ISO 10534-2 in AFD AcoustiTube®. The impedance tube setup is shown in Fig. 1. Samples were firmly placed into the holder with no leakage for sound waves to escape at boundaries. Testing was carried out across the frequency range of 50-6600 Hz and the average of 1000 runs were set on the instrument. Signal to noise ratio was maintained at 60 to 65.

4. RESULTS AND DISCUSSION

The transmission loss was observed for polymer composites reinforced with treated and untreated coir fibres. It was noticed that the transmission loss of coir fibre composites depends on the fibre fraction and surface treatment. It is described in subsequent sections and factors affecting the same have been discussed in detail.

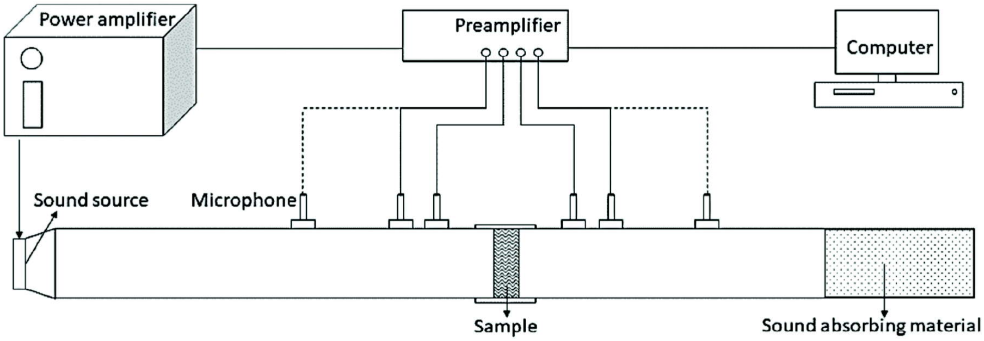


Fig. 1. Impedance tube with four-microphone arrangement

4.1 Effect of fibre loading

Circular samples of composites were placed and transmission loss was observed for different fibre loadings. It can be seen in Fig. 2(a), that transmission loss increased as the fibre loading increases from 10% to 30% in the samples containing untreated coir fibres as reinforcement.

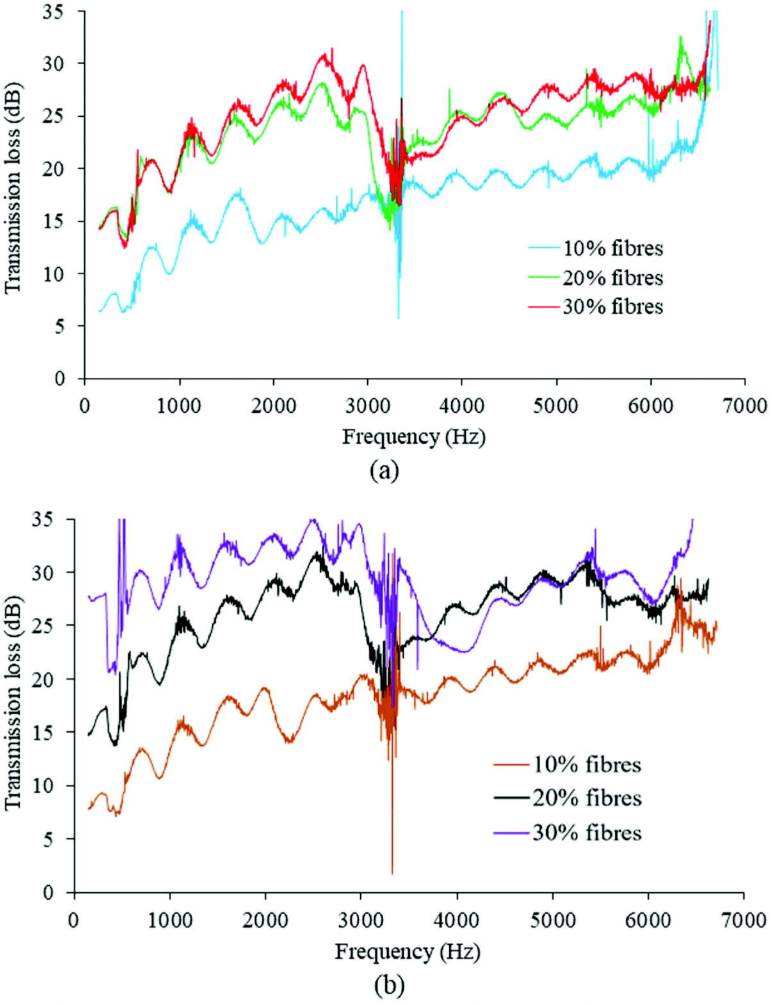


Fig. 2. The transmission loss of composites reinforced using (a) untreated coir fibres and, (b) alkali-treated coir fibres

Similarly, in Fig. 2(b), the transmission loss increases with an increase in fibre loading for composite samples having alkali-treated fibres. In both the cases, composite samples having 30% fibre loading displayed highest transmission loss whereas, samples with 10% fibre loading displayed minimum transmission loss.

The increment in transmission loss can be attributed to a higher number of fibres and thus larger areal density. This helps in the higher reflection of sound waves. Also, coir fibres have a large lumen (air cavity) which can be seen in scanning electron micrograph (Fig. 3). There is more air cavity in composite samples having higher fibre loading. It is evident from treated and untreated coir fibre reinforced composites.

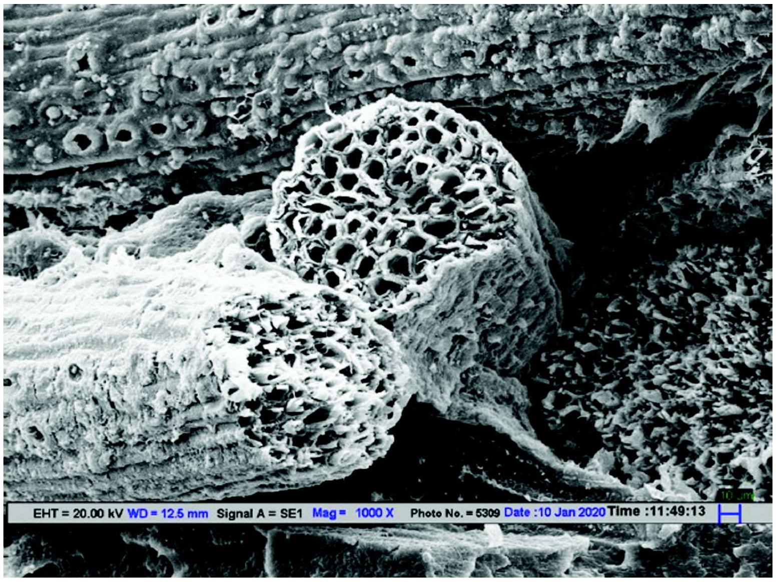
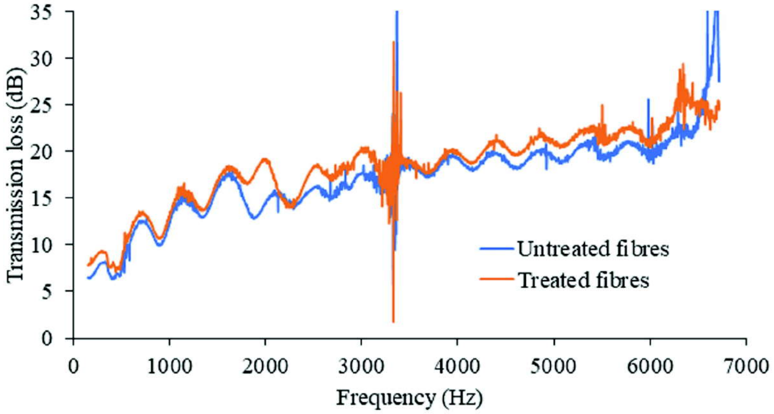


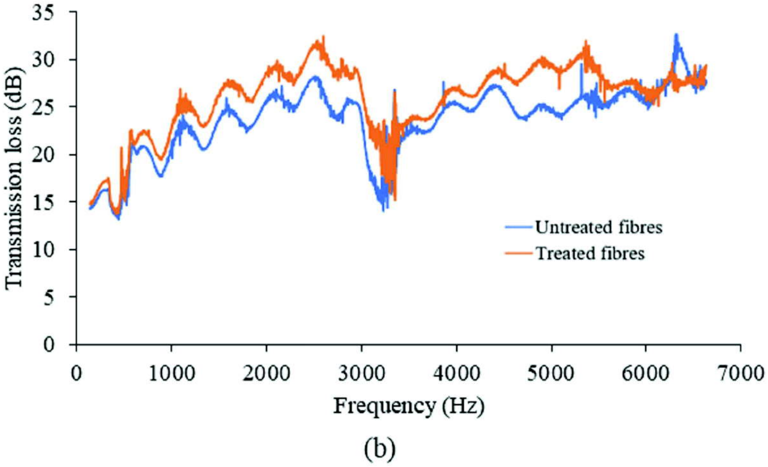
Fig. 3. Scanning electron microscope image of the cross-section of untreated coir fibres with lumen visible

4.2 Effect of surface treatment

A comparison of transmission loss of composites reinforced by alkali-treated and untreated coir fibres at fixed fibre loading is shown in Fig. 4. It can be clearly seen that the composites reinforced with alkali-treated coir fibres display higher transmission loss as compared to untreated fibre reinforced composites. However, the difference between the two is highest at 30% fibre loading.



(a)



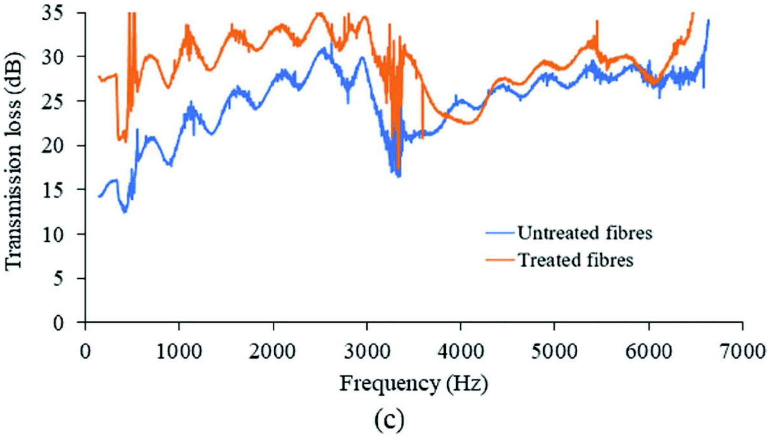


Fig. 4. Comparison of transmission loss of treated and untreated coir fibre reinforced composites, at (a) 10%, (b) 20% and (c) 30% fibre loading

It can be attributed to the enhancement in interface resulting due to alkali treatment. Coir fibres have lignin which is removed after the alkali treatment. Moreover, alkali treatment at 5% NaOH concentration reduces the fibre weight of approximately 15%. It denotes, at same fibre mass, number of treated fibres is more than untreated fibres. This, in turn, leads to more compact composite structure displaying higher transmission loss.

Also, the functional hydroxyl groups are modified after the alkali treatment as shown in Fig. 5, which makes the fibres hydrophobic. This helps in the thorough spread of matrix and thus, better interface with the matrix. This explains why composite samples at 30% fibre loadings have sufficiently high transmission loss difference.

5. CONCLUSION

Composites were fabricated at 10%, 20% and 30% fibre loading using untreated and alkali-treated coir fibres. The transmission loss of samples was observed using the impedance tube. It was noted that fibre loading and surface treatment affect the transmission loss of composites. Increase in fibre loading increases the areal density of composite samples which reflects the majority of incident sound waves. Similarly, alkali treatment resulted in better adhesion to matrix. This also resulted in compact composite

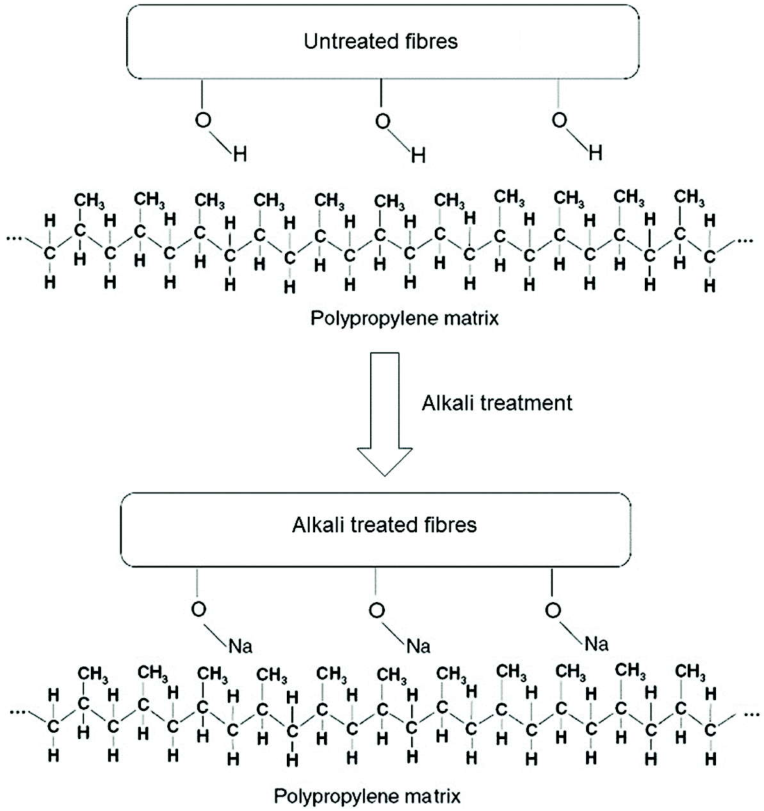


Fig. 5. Schematic of change in functional group of coir fibres after alkali treatment and their interaction with polypropylene matrix

structures leading to higher transmission loss than untreated fibre reinforced composites. It can be concluded that the sound insulation of fibre reinforced composites is dependent upon process and material parameters. These parameters can be optimised for better acoustic properties.

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Investigation of the acoustical characteristics of a newly designed room

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ABSTRACT

The study of acoustical characteristics is important to understand sound propagation, absorption, build up and aural comfort in closed and open spaces. To design a space (room, hall, lab, *etc*), the acoustic parameters such as Early decay time, Reverberation time, Noise criterion and other parameters need to be determined. These parameters help acousticians to correctly design and maintain the venues according to need. This article presents experimental investigation and analyses of the acoustical characteristics of a renovated room in the Mechanical Engineering Department of the Aligarh Muslim University (AMU). The results of experimental data collected using microphones were found to be in accordance to values set by various standards. The room was found to be suitable to be used as a lecture room and laboratory while it was unsuitable for musical purposes.

1. INTRODUCTION

Acoustical evaluation is an integral part of room design as the acoustical characteristics specify the purpose for which a designed closed space (room, hall and auditorium) is to be used. The most commonly used method for determining the acoustic parameters and evaluating sound quality is the impulse response method in which a random noise (pink noise, white noise, balloon pop sound, *etc.*) is played for a short while and is received by an omnidirectional microphone. Plotting the sound pressure levels as a function of elapsed time gives the various acoustical characteristics of space under study. In the present study, white gaussian noise has been used to generate impulse response and various softwares have been used for its analyses. Many studies have been carried out using the impulse response method to classify spaces, some of which are discussed below.

Houtgast *et al.* described in detail the implementation of an acoustical Modulation Transfer Function (MTF) analysis with a sinusoidally modulated test signal. They reported that the performance of a sound transmission system as revealed by the MTF could be expressed in one single index (the Speech Transmission Index, STI), which related well to the performance as determined by intelligibility tests with talkers and[1].

Milner *et al.* used the finite element method used to study the modal characteristics of a class of reverberation rooms with parallel floors and ceilings. They developed special numerical procedures to express acoustic finite element matrices as functions of room shape. The studies of rooms with one nonparallel wall illustrated the typical influence of room shape on the modal distribution in the room. It was concluded that many dissimilar room shapes exhibited similar performance. Their investigation also indicated that the performance of the room is often very sensitive to small changes in room configuration [2].

Hodgson performed acoustical measurements in 30 randomly chosen, unoccupied classrooms at the University of British Columbia UBC. It was shown that the UBC classroom stock was of far from optimum acoustical quality when unoccupied but was much better in the occupied condition. It was discussed that in general, many classrooms have excessive reverberation and result in low speech levels, especially at the back of the rooms. It was concluded that there was a significant effect of the presence of students on the acoustical conditions in classrooms, and there was a need to account for them in classroom design[3].

Alam *et al.* presented an acoustic analysis of Kennedy Auditorium with the active sound systems in use. The effect of the Building materials and their absorption properties was also discussed. It was reported that the RT of the Auditorium was much larger than the accepted values especially at lower frequencies and that the side walls were highly reflecting in nature and proper wall treatment was required for trapping the lower frequency reverberance. It was recommended that the existing sound system in the hall had to be optimized by proper installation of line arrays and infra subs[4].

Pelegrín-García, D., *et al.* studied the influence of four acoustically different rooms on the speech produced by 13 talkers by addressing a listener at four distances. It was found that in the most uncomfortable rooms to speak in, talkers prolonged the voiced segments of the speech they produced, either as a side-effect of increased vocal intensity or in order to compensate for a decrease in speech intelligibility. They concluded that the decision of using a certain voice level depended on the visually perceived distance to the listener and varied between 1.3 and 2.2 dB per double distance to the listener. It was further concluded that a room that provided vocal comfort required a compromise between room gain and STI, supporting the voice from a talker but not degrading the perceived speech quality[5].

Pelegrín-García, *et al.* conducted laboratory experiments in order to determine optimum room acoustic conditions for speaking. A questionnaire investigation was presented which showed that the acoustic comfort for talking in classrooms, in the absence of background noise, is correlated to the decay times derived from an impulse response measured from the mouth to the ears of a talker, and that there was a maximum of preference for decay times between 0.4 and 0.5 s. It was further found that teachers with self-reported voice problems preferred higher decay times to speak in than their healthy colleagues. It was also concluded that teachers with voice problems perceived their environment differently than teachers without voice problems, preferring higher decay times to speak in[6].

Zannin *et al.* evaluated the acoustic comfort of classrooms in a Brazilian public school through interviews, measurements of background noise, reverberation time, and sound insulation. The acoustic measurements revealed the poor acoustic quality of the classrooms. It was shown that teachers and pupils consider the noise generated and the voice of the teacher in neighbouring classrooms as the main sources of annoyance inside the classroom. Acoustic simulations resulted in the suggestion of placement of perforated plywood on the ceiling, for reduction in reverberation time and increase in the acoustic comfort of the classrooms. The classrooms would then turn acoustically acceptable, according to the values of reverberation time established not only by the Brazilian Standard NBR 12179, but also by standards of other countries[7].

2. METHODOLOGY

In lecture rooms and labs, a major acoustic concern is verbal communication as most of the activities in the lab are dependent on speech intelligibility (SI). The speech intelligibility in rooms and enclosures is related to signal to noise ratio (SNR) as well as the acoustical characteristics of the enclosures. Thus, it can be influenced by background noise (BN) and reverberation time (RT). From directional perspective, a room acoustic indicator can be placed in one of the three categories *i.e.,* monophonic, directionally influenced and directional The monophonic indicators (EDT, RT_{60}, C_{50}, STI and SNR) can be determined via pressure impulse response resulting from a single microphone measurement and interpreted by way of inferred energy expressed by squared pressure in relation to time history[8].

2.1 Description of Room

The room under study was renovated under DST project and is in the main building of Zakir Hussain College of Engineering and Technology, AMU. The room measures 26×21×16 ft and has two windows (3.75×2.6 ft) and one door (7×4 ft). Two window ACs and three fans are installed in the room (fig. 1). The maximum capacity of the room is x pupils. It can be used both as a lecture room as well as an acoustics measurement laboratory. The floor is covered with ceramic tiles and there is no false ceiling installed in the room. The walls of the room are made of brick, plastered with cement mortar and painted with white distemper. No acoustical treatment has been applied in the room. Sabine's reverberation time[17] is 2.5s.

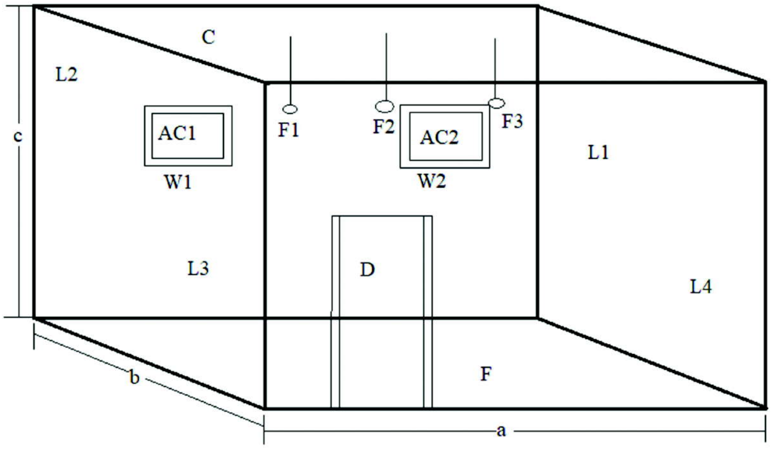

Fig. 1. Layout of the room; a= 7.92m; b= 6.4m; c= 4.88m; F1, F2, F3= Fans; C=Ceiling; F= Floor; W1, W2= Windows; AC1, AC2= Air conditioners; D= Door; L1,2,3,4= Walls.

2.2 Experimental Setup

To measure the monophonic parameters (listed in table 2), a two-channel SDG 1032X (SIGLENT) waveform generator has been used, which generates a gaussian white noise signal to a BAS-001 (Larson and Davis) power amplifier connected to the sound source. A dodecahedral omnidirectional sound source was used. The generated sound was captured by a random incidence microphone (PCB PIEZOTRONICS) connected to the NI 9215 DAQ Assistant via a signal conditioner (Experimental setup shown in fig. 2).

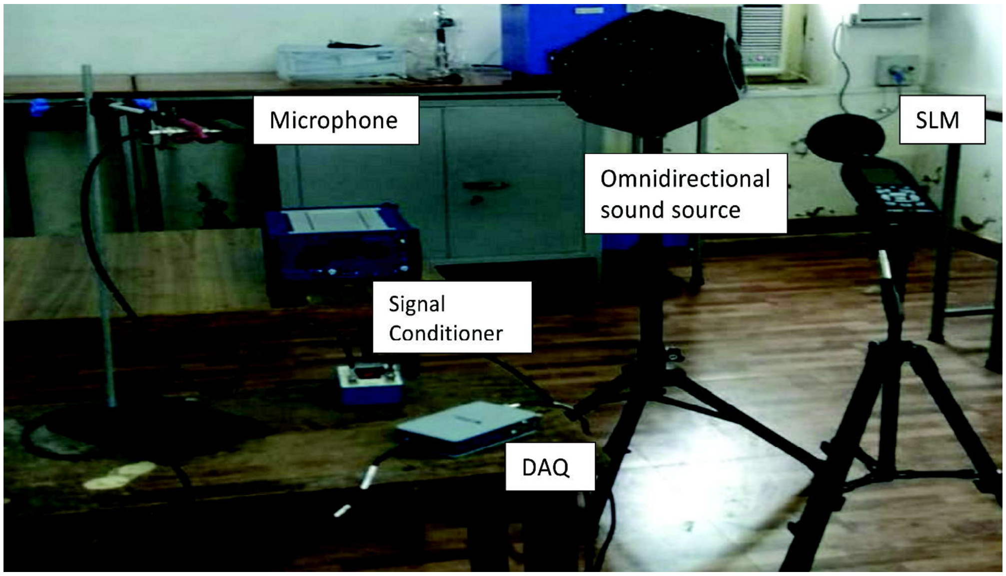

Fig. 2. Instruments Used

The impulse response was acquired using Lab View. MATLAB codes were then used to calculate different parameters. The measurements were taken following the specifications of the ISO 3382 standard[15].

Before the calculations of EDT and RT_{60}, the Impulse Response was band-filtered in 1/3 Octave Bands with centre frequencies (fc) ranging from 125Hz to 8kHz. All the calculations were made according to the methods mentioned in table 1. Measurements were taken at six different points in each classroom under four different conditions: ACs and fans ON (S1), ACs ON and fans OFF (S2), ACs OFF and fans ON (S3), ACs and fans OFF (S4).

2.3 Background Noise and Noise Criterion

Background Noise is one of the parameters that affect the acoustical comfort of classrooms. There are established recommendations limiting background noise in several countries such as Brazil, France, Germany, United Kingdom and the USA. Limiting background noise level in India is 55 dB during day and 45 dB during night (according to the Indian standard NBC 2005).

Background noise was measured using a sound level meter (Larson and Davis Soundtrack L×T1) at six different locations in the room (as mentioned in section 2.2.) and Noise Criterion was established using the same data.

3. RESULTS AND DISCUSSION

3.1 Noise Criterion

The values of A-weighted background noise levels (Leq) and the corresponding noise criterion (NC) for the four situations S1, S2, S3 and S4 are listed in table 1. Each value was obtained by using the SLM and recording the data for 20 seconds. It was observed that Leqs for all cases except S4 were much higher than the recommended values. This was due to the noise coming from the fans and air conditioners. On the other hand, Leq for S4 was well tolerable, hence the room seems to be well insulated from outside noise. This implies that the room is ideal for listening when there are no electronic equipment operating in it, however, this is only possible in winters when there is no need of cooling. Under the conditions of fans and ACs operating, it becomes essential to provide for sound insulation inside the lab so that the noise levels could be minimised.

Table 1. Background Noise for different situations in the room.

Situation	NC	Leq (dBA)
S1	63	67.7
S2	60	63.4
S3	60.2	64.7
S4	30.6	41.5

The NC curve for S1 is shown in figure 3. Similar NC curves were used to calculate NCs for the other three situations. Noise criterion is only found suitable for S4 implying that the relative noise levels for the octave frequencies are much higher than acceptable values for S1, S2 and S3. Unacceptable NC may create fatigue and negatively affect productivity and the ability to communicate.

3.2 Monophonic and 1/3 Octave Band filtered Parameters

According to the Indian standard IS: 2526-1963, the recommended reverberation time for speech category rooms of size comparable to the one under study is about 0.9s. Sabine's relation yields RT60 for the room to be 2.5s, which is due to poor or no acoustical treatment on surfaces of the room and the absorption coefficients are lower due to the presence of mostly reflecting surfaces. High reverberation time also increases the background noise and hampers the speech intelligibility in classrooms.

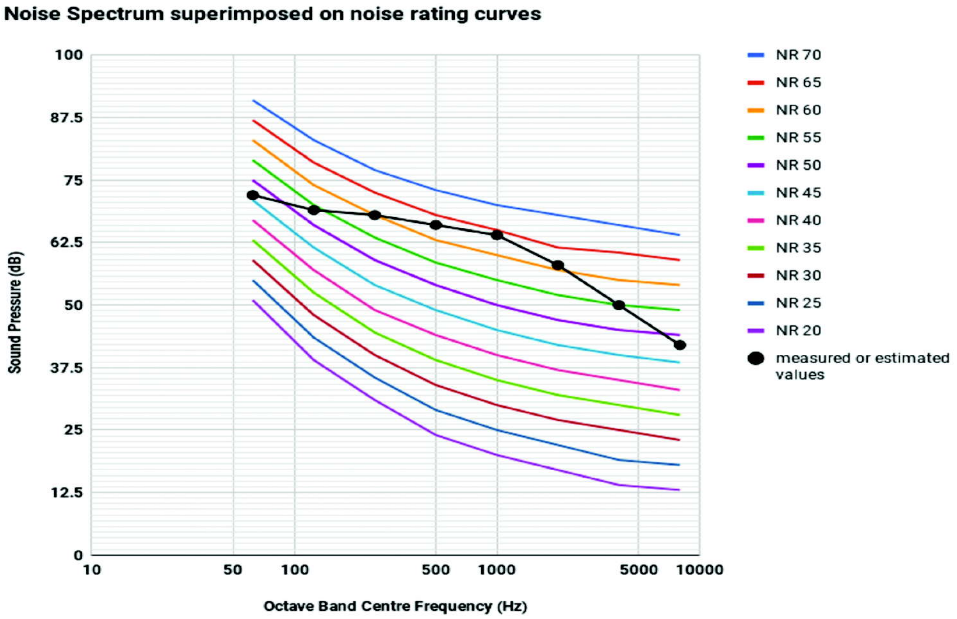

Fig. 3. Noise Spectrum superimposed on noise rating curves for S1

Summary of RT_{60} and EDT measured in six locations at frequencies ranging from 125 Hz to 8 kHz are shown in Table 2. The decay level (shown in figs. 4-6), RT and EDT were calculated using Schroeder's model. EDT was calculated using the slope up to 10dB drop while RT_{60} was calculated using slope between 15 and 35 dB drop. It was observed that the RT is high at lower frequencies for all the six locations (shown in fig. 7) in the room depicting low absorption of low frequency sounds. Larger values of EDT than RT indicate lower clarity of sound and low speech intelligibility[11]. RT_{60} was in compliance with the Indian standard for the medium frequency range (500-2000Hz). For other centre frequencies, the RT was much higher which indicated poor sound absorption at both low and high frequencies. However, human ears are more sensitive in the medium frequency range, thus the reverberation characteristics of the room are suitable for hearing.

The mismatch between Sabine's RT and the calculated RTs maybe due to the presence of experimental equipment, apparatus, tables and other furniture in the room. These equipments, to some extent provide absorbing surfaces which result in the lowering of RT. It can thus be inferred that even though there is no acoustical treatment in the room, the presence of the above said stuff acts as sound absorber and makes the room suitable for hearing lectures. From figs. 5-11 it is observed that Schroeder's model is more applicable at fc=2k-8kHz as the decay curves are smoother at these frequencies and follow the

Table 2. Various monophonic parameters at different locations in the room.

Location	Unfiltered EDT60(s)	Unfiltered RT60(s)	R	C50 (dB)	D50	STI	% ALcons
L1	2.18	0.83	20.69	-21.88	0.112	0.7148	3.5465
L2	2.12	0.76	23.41	-24.33	0.087	0.7152	3.5386
L3	2.24	0.78	21.58	-22.68	0.103	0.7683	2.6535
L4	2.82	0.92	23.64	-24.54	0.086	0.7644	2.7106
L5	1.5	0.67	22.4	-23.41	0.087	0.9008	1.2947
L6	2.56	0.82	22.31	-23.33	0.097	0.7161	3.5212
Average	2.24	0.79	22.34	-23.36	0.095	0.7633	2.8772

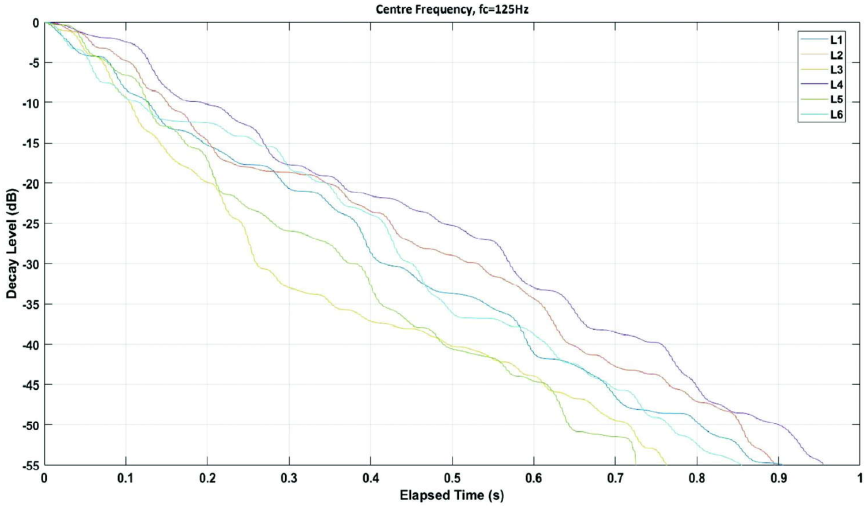

Fig. 4. Decay level at centre frequency, fc=125 Hz.

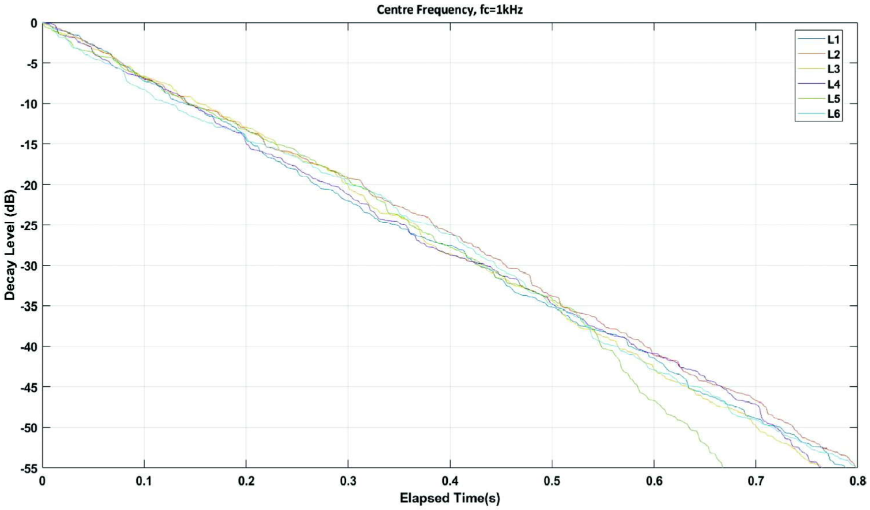

Fig. 5. Decay Level at centre frequency, fc=1000 Hz.

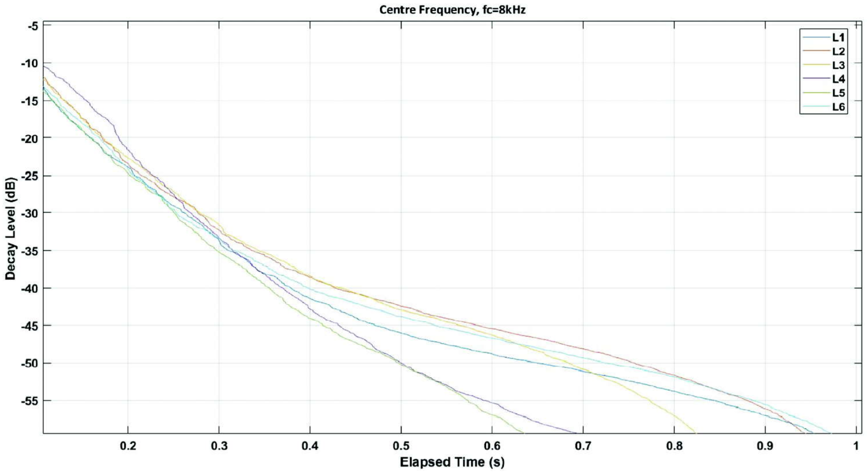

Fig. 6. Decay Level at centre frequency, fc=8000 Hz.

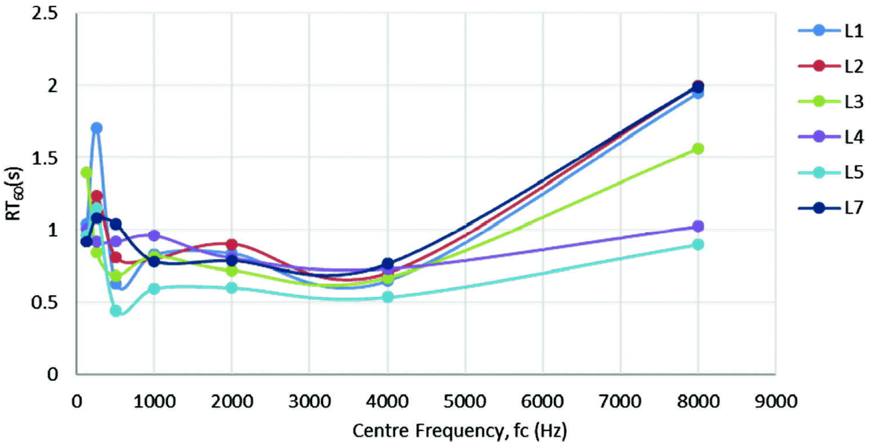

Fig. 7. Reverberation time v/s centre frequency for different locations.

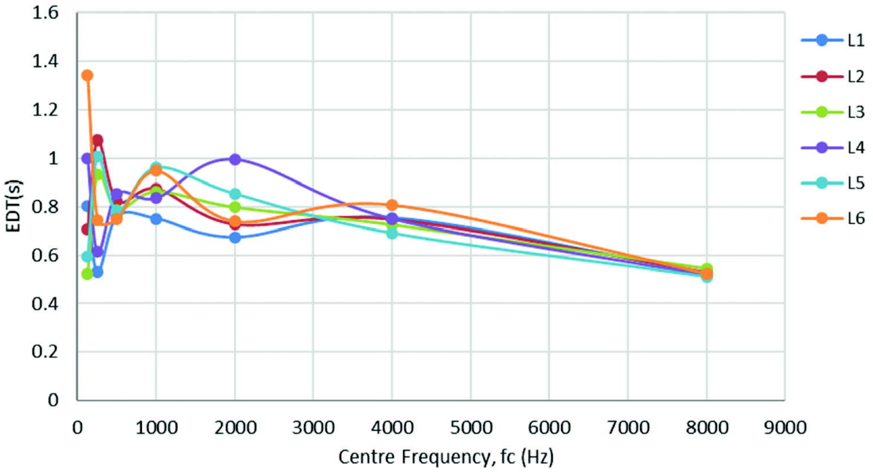

Fig. 8. Early Decay time v/s centre frequency for different locations.

characteristics of Schroeder's curve as well. This implies that the results obtained at these three frequencies are more reliable. However, the values of results at other frequencies are close to these values, therefore all the measured values are accurate and the methods used in experimentation are reliable. The fluctuation in the decay curves at lower frequencies is due to poor absorption and scattering of low frequency sound.

The average values of R, C_{50} and D_{50} (Table 2) are much beyond the tolerance bounds[9-11]. Thus, the room is unsuitable for musical events as a greater value of C_{50} gives music a sensation of definition (D_{50}), while decreased definition adds 'fullness of tone'. In concert halls, lower value of definition is preferred, but the average measured D_{50} is even lower than the desirable value[11]. Furthermore, high values of EDT are preferable for concert halls while the trend is reversed after 2s, this again makes the room unsuitable for music as most of the values of EDT are greater than 2s. The STI of the room has an average value of 0.76 which implies that the speech intelligibility of the room is quite good. Even though the D_{50} was very less, the measured STI was within good range of intelligibility; this is due to the high value of signal to noise ratio (SNR=55 dB) which directly influences the value of STI. It is to be noticed that SNR alone is not a measure of STI, it is also affected by band filtered RTs and modulation frequencies. In the current study, the combination of the measured RTs and STI indicates good quality of sound and intelligibility but inappropriate clarity. It can thus be inferred that the room is suitable to be used as a classroom or a laboratory but unsuitable for musical purposes. Precise requirements for good room acoustics include adequate loudness, uniformity, clarity, reverberance, freedom from echoes, and minimal background noise.

Thus, the optimum acoustical quality is a compromise between clarity (requiring short reverberation time), sound intensity (requiring a high reverberant level), and liveness (requiring a long reverberation time).

4. ACKNOWLEDGEMENT

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Investigation of low frequency sound absorption property of fluorogypsum material for indoor applications

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ABSTRACT

The present study deals with the sound absorption property of fluorogypsum (FG) material over the audio frequency range of 70 - 1000 Hz. The maximum noise reduction coefficient (NRC) for the perforated FG sample is obtained as 0.8 over the frequency range of 250 - 300 Hz and the average value of NRC is 0.48 for the perforated sample of 10 mm thickness. Whereas, the non-perforated fluorogypsum material shows very low NRC values, highest being 0.34 and average 0.22 over the audio frequency range of 70 - 3000 Hz. The higher frequency regime from 3500 - 6600 Hz gives the average NRC value of 0.10. The other parameters like porosity, tortuosity and flow resistivity of FG sample have been theoretically studied and discussed. Therefore, perforated fluorogypsum material has a potential application sound absorption in a lower audio frequency range which can effectively suppress noise pollution of road transportation, human conversations, and other ambient noise sources.

1. INTRODUCTION

In today's Indian scenario, increasing urbanisation has led to various environmental pollution like air, water, soil, and noise. Among all types of pollution sources, noise is considered to be one of the underestimated pollution causes which have adverse effects on urban population. In the past few years, noise pollution has become a major concern for health issues for the population living in urban areas. The world health organisation (WHO) has classified noise as a major pollutant that is affecting the health of vast population. It can result in serious health problems which include hypertension, ischemic heart disease, hearing problems, and even permanent hearing damage if exposed to high noise levels for a long period of time[1-5]. The most common form of noise pollution is road traffic noise (airborne noise) and it mainly affects the nearby population. Few researchers have studied the effects of road traffic noise in India mentioned elsewhere in detail[6-8].

Noise pollution source can be broadly classified into two categories namely: community noise and industrial noise. The vehicular noise, firecrackers, loudspeaker, and human conversation falls in community noise class whereas, noises from heavy machinery from industrial area falls in industrial noise class. According to a report by Central Pollution Control Board (CPCB), India, on festival occasions the noise and air pollutions due to firecrackers rises very sharply and affects many living populations[9, 10].

To minimise the noise pollutions and bring it to the normal comfort level of living, there are several ways such as passive method which employs a noise-resistant material to prevent the sound from source to destination. The other method is active noise control method which relies on cancelling the unwanted noise by interfering with them. The passive method is the most common solution for noise control phenomenon as compared active method. Many materials such as polymer foams, fibers, gypsum boards, mats, perforated metal sheets, glass wool, mineral wool, cork-based materials, and aerogels are considered to be good sound-absorbing materials[11-17].

The suppression of low-frequency noises is of great interest in the commercial and residential buildings. Since high-frequency sound waves when interacts with the porous material loses a significant amount of energy. But low-frequency noises can easily pass through the noise barriers. Therefore, now the focus is on the materials with double layer of porosity at the microstructural level and by mechanical perforations. To enhance the absorbing property or sound attenuation of material at specified frequencies of composite materials like hemp, reed, and polymer foam particles in the main matrix are now being employed in practical solutions[18]. Different level of porosity and material properties plays an important role in sound absorption. Even the pore size and its elongation play a very important role in acoustic absorption[19]. Gypsum material in the form of panels is the most widely used sound absorbing material since it is easy to fabricate at lower cost as compared to organic porous materials which cannot withstand higher temperature. Typical inorganic materials such as glass wool and rock wool have good sound attenuation properties but being fragile in nature poses risk of health hazard at high temperatures. Natural cork is also one of the fine acoustic absorbers with tolerance at high temperature but limited to its local availability and high pricing. On the other hand, the metallic porous materials provide excellent sound absorption properties with high temperature sustainability, no harmful products at a higher temperature but at a higher cost. In a study done by Cuiyunet *et al.,* 2012 on zeolite-based materials, they have found that zeolite at high sound frequencies has good sound absorption properties with absorption coefficient as high unity[20].

Most common example of sound absorbers is in the form of the false ceiling tiles which employ gypsum, cork or composite foams as raw materials. Cork being a natural material has a very good sound absorbing as well as fire resistant properties and is expensive. Foam based materials also show high sound absorbing features but are not fire resistant[17, 20]. Gypsum on the other hand is inexpensive and naturally abundant material in most parts of India where it is obtained from mining. Since mining of gypsum has led to environmental concerns, the focus has been shifted to gypsum obtained as waste from coal industries, acid industries like hydrofluoric, phosphoric and fertilizer industries. If not disposed or used properly, this waste will create landfill problems which will ultimately affect the whole ecological cycle of that particular area. Gypsum production from natural resources or from various industries has been listed and mentioned elsewhere[21]. Fluorogypsum material has been found important applications in building materials in the form of bricks/blocks, binder and plasters[22].

The gypsum (calcium sulphate dihydrate) has chemical formula as $CaSO_4.2H_2O$. The main composition of the natural gypsum is CaO 32.5 wt %, SO 46.6 wt% and H_2O 20.9 wt % with small amounts of clay, silica, chalk and iron compounds. Gypsum is cured at 150-165°C for 2-3 hours in order to make it hemihydrate *i.e.* $CaSO_4.0.5H_2O$. The material properties of fluorogypsum and phosphogypsum have been done in detail and described elsewhere[22]. Natural gypsum or synthetic gypsum is a recyclable and green material and therefore it is environmental friendly.

The aim of the present study is to investigate the sound absorption property of fluorogypsum (FG) material in the low audio frequency regime by acoustic impedance tube method. The morphological feature of fluorogypsum material is also studied by field emission scanning electron microscopy (FE-SEM) technique.

2. METHODOLOGIES

2.1 Materials

FG sample was obtained from M/s Navin Fluorine Industries, Bhetan Gujarat. The chemical compositions of the FG material show pH: 5.0, fluoride content :1.32 wt%, SiO_2: 0.65 wt. %, $Al_2O_3 + Fe_2O_3$: 0.65 wt. %, CaO: 41.19 wt. %, SO_3: 56.13 wt. %. For the synthesis of FG samples of 100 mm diameter and 10 mm thickness, 200 gm of-fluoro gypsum with additives like $Ca(OH)_2$: 3 wt %, Na_2SO_4: 1 wt % and $CaCl_2$: (fused) 0.5 wt. % were mixed with 130 ml of water thoroughly for two minutes. After mixing, the sample mixture was cast in 100 mm and 10 mm thick mould and left for overnight drying at room temperature. The mechanical perforations were done on the sample surface to a depth of 5 mm as shown in Figure 1. The pore shape (mechanical perforation) in the FG sample is in the form of step pyramid rather than cylindrical shape as shown in Figure 1. This pore shape has advantage of creating more resistive path to flow sound wave as it travels inside the material resulting in better sound absorption.

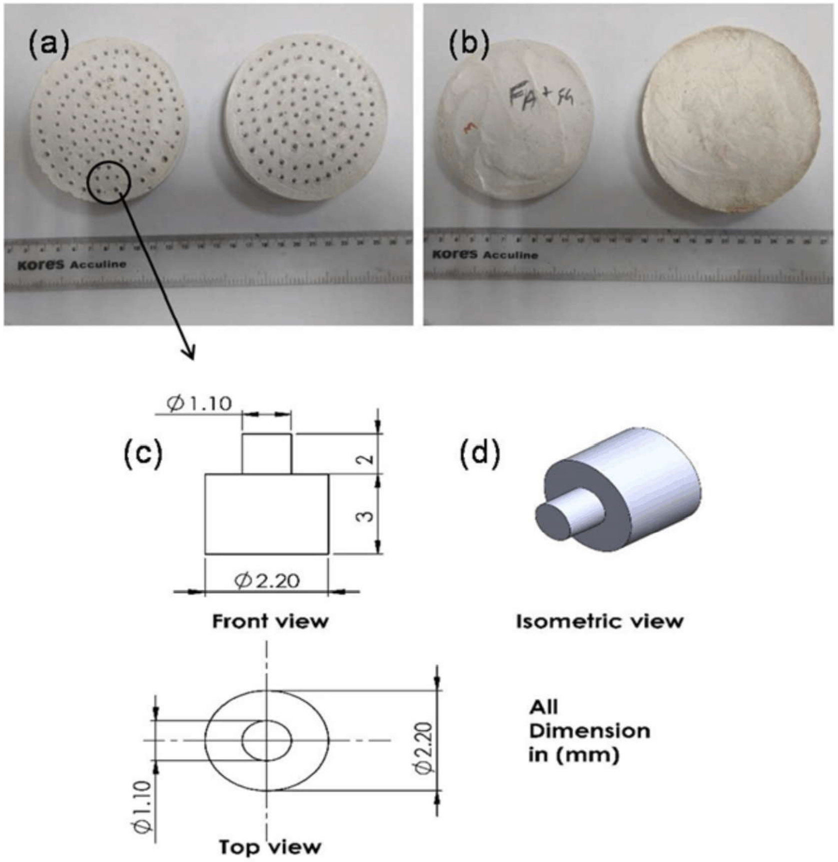

Fig. 1. (a) Perforated fluorogypsum test specimens of 100 mm diameter,
(b) non perforated test specimen of 100 mm diameter
(c) and (d) dimensions and designed perforation shape and for soundattenuation.

2.2 Equipment

Microstructure analysis samples were recorded using field emission scanning electron microscope (MIRA TESCAN 3) at an accelerating voltage of 10 kV. For sound absorption, reflection and transmission loss measurements AED 1000-Acousti Tube was used (Germany). The sound absorption coefficient of the perforated and non-perforated gypsum sample was done in accordance with ISO 10354-2 for diameter of 100 mm and 30 mm and 10 mm thick cylindrical sample. The frequency ranges for testing of the sample was in the range of 50 Hz to 2000 Hz. The sound transmission class (STC) of the non-perforated gypsum test sample of 10 mm thickness was also done. The STC is a single value obtained from the transmission loss curve at 500 Hz. The obtained NRC and STC data were analysed by AED 1401 software.

3. RESULTS AND DISCUSSION

3.1 Solid Model

Figure 2 shows the microstructural images of the FG samples cured at 40 °C for 28 days. From the figure, it is evident that small number of micropores of size 200 to 500 nm approximately can be seen on the surface in Figure 2(a) to 2(d). Figure 2(e) and 2(f) show the microstructural images of mechanically perforated FG samples of outer diameter 2 mm and inner diameter of 1 mm approximately. Due to less number of microstructural pores on the FG sample surface, the FG sample may act as a sound reflector rather than a sound absorber in the absence of mechanical perforations. Therefore, mechanical perforations have been done to increase its sound absorption properties.

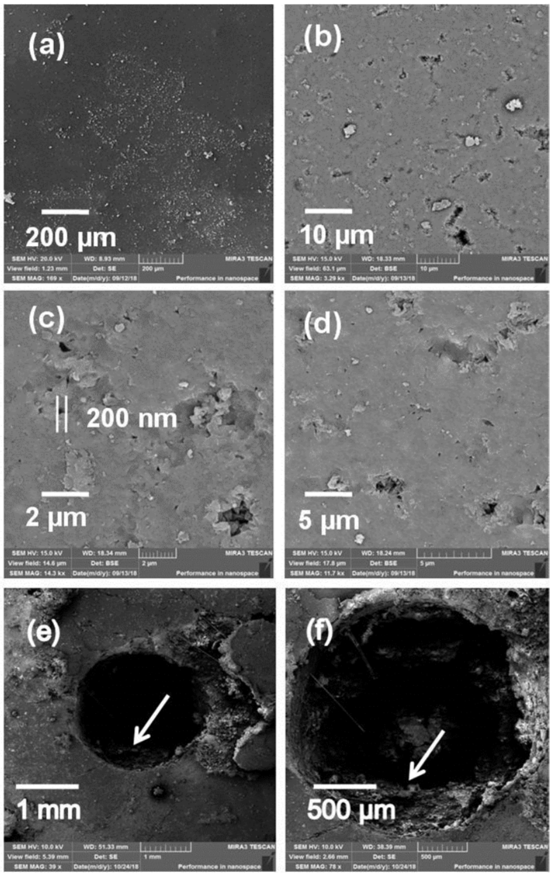

Fig. 2. FE-SEM images of fluorogypsum samples cured at 40°C for 28 days (a) to (d) showing fine microstructural pores on the surface (e) and (f) mechanical perforations on 100 mm test specimen.

The sound absorption coefficient (α_0) for normalized incident of sound wave may be written according to equation[16]

$$\alpha_0 = 1 - \left[\frac{z'-1}{z'+1}\right]^2 \qquad (1)$$

where Z′ is the normalised surface impedance of the material and can be expressed as Z_s/Z_{air}, Z_s is the specific acoustic impedance on the material's surface and Z_{air} is characteristic impedance of air. The Z′ is a dimensionless complex quantity.

Figure 3(a) shows the sound absorption or noise reduction coefficient (NRC) values and reflection coefficient of FG sample in the frequency range of 50 Hz to 1000 Hz. It is clearly evident from Figure 3(a)that the NRC plot has peaks and valleys' suggesting that absorption phenomenon is not constant over the entire frequency range. Figure 3(b) represents the reflection coefficient plot showing an inverse trend of peaks and valleys over the same test frequency range implying dominance of one particular phenomenon in a given frequency range. In the frequency range of 250 to 300 Hz the sound absorption coefficient has a maximum value of 80 percent and almost 40 percent absorption at 400 Hz. The frequency range of 250 to 500 Hz is the main cause of speech disturbances in speech communication. With the above sound absorption coefficient values, the FG test samples show effective sound absorption at relatively lower frequencies.When compared with 20 mm thick mineral wood board the absorption value at 250 Hz is 0.1 and 0.4 at 500 Hz which is clearly less than the value obtained for FG samples[14]. Figure 4 shows the normalised complex acoustic impedance plot of perforated gypsum sample. At lower frequencies *i.e.* 200 - 400 Hz the real plot of the acoustic impedance curve has low acoustic impedance values suggesting a better interaction of sound wave with the material. Better interaction of sound waves with the material will lead to more dissipation of sound energy in the pores and hence the sound absorption will be enhanced. The NRC data for non-perforated FG sample has also been plotted and shown in Figure 5. The NRC values of non-perforated FG test sample for 10 mm thickness shows inferior sound absorption as compared to the perforated sample of same thickness. This shows that the microstructural pores on the surface are much smaller in diameter so as to interact and absorb the sound waves incident on the surface.

The transmission loss (TL) also known as sound transmission class (STC) of non-perforated FG sample is shown in Figure 6. The STC value is usually measured at 500 Hz. In the present study of non-perforated gypsum sample, the value is 18 dB. The larger the STC value, the better is the partition, *i.e.* less sound energy passes through the partition sample. The sound transmission loss generally increases with the incident sound wave frequency and varies with the direction of the sound waves. Therefore, on the basis of above results, we can say that non-perforated FG samples show less STC values and have to be structurally modified so as to provide a good transmission loss rating.

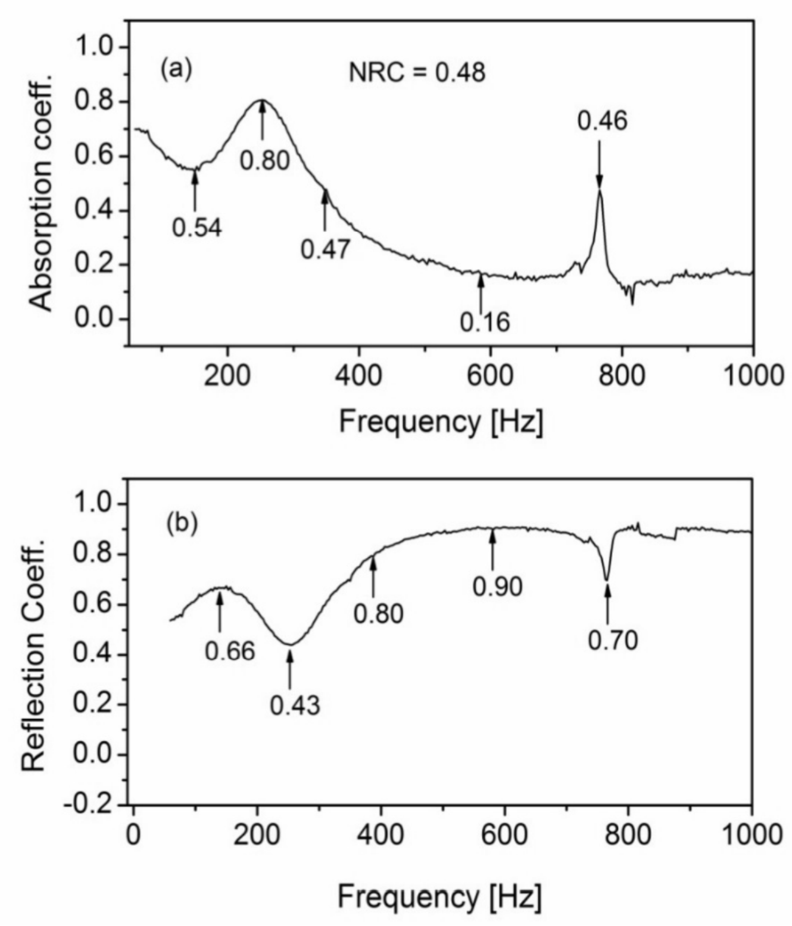

Fig. 3. NRC and reflection plot of perforated gypsum sample.

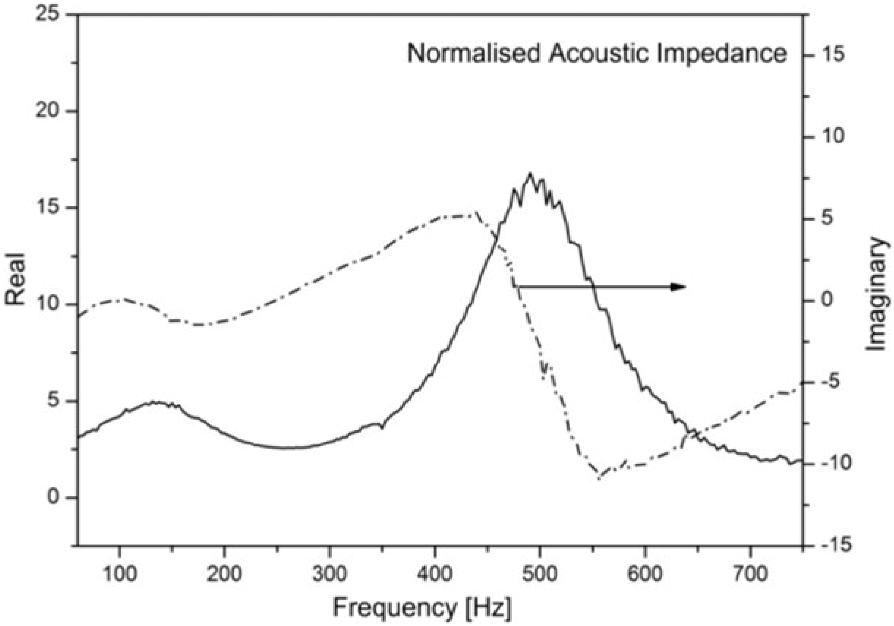

Fig. 4. Normalised acoustic impedance plot for perforated gypsum.

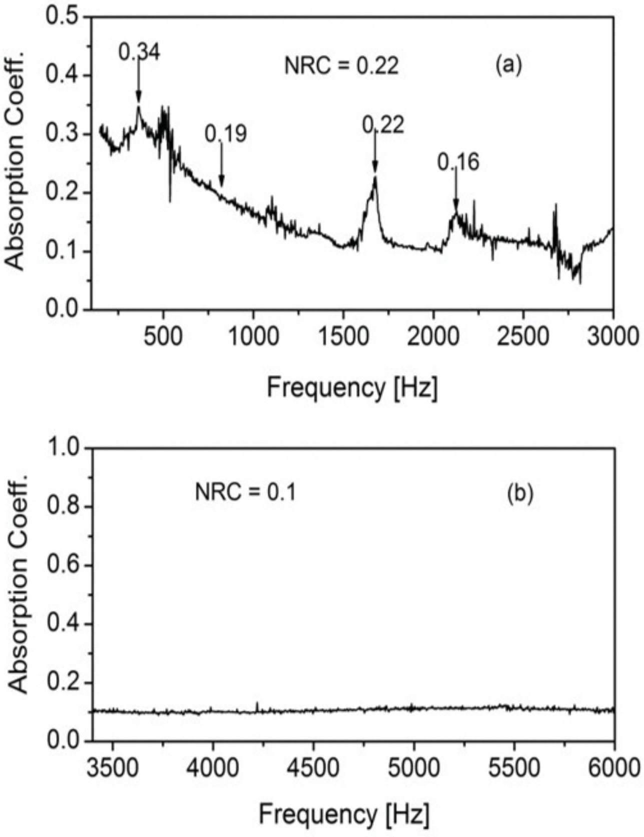

Fig. 5. NRC plot of non-perforated gypsum sample in low and high frequency range.

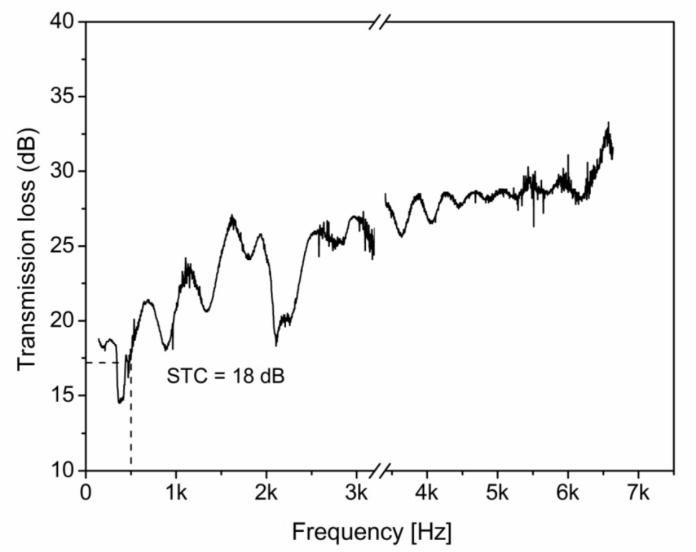

Fig. 6. Transmission loss curve of non-perforated gypsum sample.

3.2 Acoustic parameters calculations: Tortuosity, porosity and air flow resistivity

The sound absorption property of porous FG material depends mainly on porosity (ϕ), flow resistivity (σ), tortuosity (α) along with viscous and thermal characteristic length[23]. In the present study, the mechanical perforation has covered the surface area of the FG 100 mm diameter sample is approximately six percent of its total surface area. The dissipation of sound energy depends upon number of pores, its size and shape. When a sound wave interacts with porous material, the air volume inside the pores acts as a spring and its opening acts a mass and creates a damping effect resulting in attenuation of sound energy. The elongation of pores through which sound wave travels in the material and dissipates the energy is known as tortuosity (τ) and can be written according to the formula.

$$\tau = 1 + 0.65 \ \frac{(1-\phi)}{(\phi-\phi_c)^m} \tag{2}$$

where ϕ is the porosity of the material and m is the exponential constant which has a value of 0.19 and ϕ_c is the percolation threshold[24] = 0.33.

The porosity of the FG (including microstructural and mechanically perforated pores) sample may be calculated as

$$\frac{V_{pores}}{V_{total}} \tag{3}$$

where V_{pores} is volume of the pores, V_{total} is the total volume of the sample including pore volume and Vsolid volume of the solid portion of the sample. Total pore volume can be written as:

$$V_{pores} = V_{total} - V_{solid} \tag{4}$$

In the present study, the overall porosity comes out to be 0.42. Putting the above values in the equation (2) the value of tortuosity (τ) is calculated as 1.5. For a porous structure, the value of ? should be greater than one. Airflow resistivity is another important parameter in sound absorption. It measures how easily sound wave (air) can enter in a porous structure and the resistance it meets during its flow in the structure, it can be written as

$$r_f = \frac{R_s}{d} \tag{5}$$

where R_s is the specific flow resistance (Pa.sec/m) and d is the thickness of the material.

The value of flow resistivity can also be calculated on the basis of Delany and Bazley's model and can be written as [16]

$$Z_c' = (1 + 0.0571\, C^{0.754}) - i\,(0.087\, C^{0.732}) \tag{6}$$

Where $C = r/\rho_0 f$. r is the airflow resistivity in Pa.sec/m^2, f is the frequency in Hz and ρ_0 is the density of air in kg/m^3 (1.2 kg/m^3). The value of C lies in between 0.01 to 1.0 [m^3/kg]. The calculated value of rat 200 Hz is 120 Pa.sec/m^2 and is in agreement with the existing literature[16]. At higher frequencies, the value of flow resistivity will enhance but will lead to lower value of absorption coefficient. The reason may be attributed to greater difficulty in the movement of the sound waves in the material which will make the surface reflective instead of absorptive.

4. CONCLUSION

Low frequency sound absorption of mechanically perforated fluorogypsum (FG) sample is studied in the present study. At lower frequencyrange of 200- 300 Hz, the 10 mm thick FG sample shows high NRC coefficient of 0.8 (0.48 in the frequency range of 100 to 1000 Hz) suggesting effective absorption of low frequency noises which can interfere in speech communications. The low value ofnormalised acoustic impedance of FG sample surface in the low frequency range leads to greater dissipation of sound energy inside the material resulting in high sound absorption. For the non-perforated FG sample, the sound absorption coefficient value is 0.22 over the frequency range of 100 to 3000 Hz and 0.1 in the high frequency range i.e. 3500 to 6000 Hz. The various parameters like porosity, air flow resistivity and tortuosity are also calculated and are in agreement with the previous studies. The fluorogypsum prepared panels with specific designed perforations studied in the present study may be employed as low-cost sound absorbers in indoor applications.

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