BUILDING RESEARCH JOURNAL

VOLUME 60, 2012 NUMBER 1 – 2

PERFORMANCE OF SOUND TRANSMISSION ON COCONUT FIBER IMPREGNATED CAVITY FERROCEMENT PANELS WITH AND WITHOUT ABSORPTIVE MATERIAL USING STATISTICAL ENERGY ANALYSIS

P. SENTHILKUMAR [1], S. KANDASWAMY [2]

Lightweight building materials like ferrocement are used in a low cost and cost effective construction in the developing countries. Sound transmission studies were conducted on the ferrocement panel system with different types of reinforcement fibers. In this work sound reduction index and transmission behavior studies were conducted on cavity fiber impregnated ferrocement panels with and without absorptive material in the cavity.

The panels were erected as slabs and lifted and placed in the opening provided between source and receiver rooms. Sound transmission studies were conducted on panels in the transmission loss suite which was specially constructed for this set of measurements. Two coconut shell fiber impregnated ferrocement panels with the cavity thickness of 50 mm between them were cast. Fiber glass wool of 50 mm thickness and density of 48 kg/m^3 was used inside the cavity of the ferrocement panels. It has been found that the mass increase of ferrocement panels by providing cavity and absorptive material between two panels with the same thickness of 20 mm gives 10 dB difference in Sound Reduction Index (SRI). The results were then compared with the theoretical data using Statistical Energy Analysis (SEA).

Keywords: sound transmission, coconut shell fiber impregnated ferrocement panels, sound reduction index, statistical energy analysis

1. Introduction

Sound transmission in buildings is one of the major problems that are faced all over the world. Due to the development of building materials used in construction the acoustical properties of these new materials need to be studied. The era of high raised buildings in construction industries requires the use of lightweight building materials like hollow blocks and panels for their easier and cost effective construction. These lightweight materials can possess good thermal and acoustical properties. The use of agricultural wastes as granular in ferrocement panels open a new range of possibilities in the use of materials in construction industry. Considering the use of agricultural

1 Assistant Professor, Civil Engineering Department, RMK Engg College, Chennai, India,
e-mail: senthilkumarp.81@gmail.com
2 Acoustic consultant, P. S. Subramanian associates, Chennai, India

waste materials such as coconut shell as aggregates in hollow blocks and lightweight panels, there is a need to study not only the strength but also the thermal and acoustical properties of materials.

Advances in agricultural waste management resulted in alternative construction materials as a substitute to traditional materials of bricks, blocks, tiles, aggregates, ceramics and finishes like cement, lime, soil, timber. From the earlier studies on the materials it was proved that the materials with fiber components with increased porosity perform as a good absorptive material for acoustical and thermal properties. In this study coconut shell fibers are used to find a new composite building material which performs acoustically.

Researchers Mannan et al. (2007) investigated in the past used agriculture wastes such as saw dust ash, rice husk ash, palm-oil fuel ash and bagasse ash as substitutes of cement. Natural fibers can be used in concrete to produce particle boards, roofing sheets, and partition panels. In low-cost lightweight structures, agricultural waste as coarse aggregate together with cement matrix can meet design specifications.

The measurement of sound transmission from the room surfaces in buildings having lightweight elements was conducted earlier (Macadam, 1976). In case of lightweight elements a direct method was used to measure the sound transmission and the magnitudes of inaccuracies involved in its use. Lightweight walls and floors which do not rely on mass to prevent sound transmission were investigated by Craik (1988). This required the knowledge of lightweight material properties used and the details of construction.

Experiments were carried out to determine the sound transmission in the double wall cavities and isolated cavities (Sean Smith, 1997). Parametric surveys were undertaken to analyse changes to the sound transmission through these structures when the material or design parameter is altered. Variation in bending stiffness and hollow block material parameters cause a wide coincidence valley at low frequencies (Fringuellino and Sean Smith, 1999).

2. Material characteristics

In this study the coconut shell was partially used by replacing the aggregates used in construction. The coconut shell of similar age and stored under completely dry conditions was used for the study. The crushing machine designed with sieves of 4.75, 2.36, 1.7 and 1.18 mm was used in order to get shells sizes similar to aggregates used. Crushed coconut shell fibers passing 2.36 mm sieve were used for this study and 50 % of weight of the sand aggregate was replaced with coconut shell fibers. The coconut shell fibers were cured in water for 24 hrs in order to avoid the water absorption and maintain the required water cement ratio. The cured coconut shell was dried and external water was removed under atmospheric conditions one hour before the construction.

Cement mortar of 1:1:1 cement, sand and coconut shell fibers ratio was used in casting the specimens. The panel was made up of two layers of chicken mesh (22 gauge thick with hexagonal openings) and one layer of weld 100 mm x 100 mm mesh. The size of the panel tested in the transmission loss suite is as follows: 2 100 mm x 3 000 mm walls were cast for testing their sound reduction index. The study focuses on the sound reduction index characteristics of ferrocement panel made with coconut shell. The Sound Reduction Index (SRI) was measured for three different walls in which more detailed measurements were carried out: coconut fiber impregnated ferrocement panel, coconut fiber impregnated ferrocement panel with cavity and coconut fiber impregnated ferrocement panel with cavity and glass wool insulation. Two fiber reinforced ferrocement panels with cavity thickness of 50 mm between them were cast. Fiber glass wool of 50 mm thickness and density of 48 kg/m^3 were inserted inside the cavity of the panels. The ferrocement panel specimens and their sound reduction index were studied.

3. Experimental Investigations

Sound insulation is strongly dependent on the stiffness of the panel, which is different along the principal directions, depending on the panel design. To facilitate this study a transmission loss suite described in Figures 1.a and 1.b was constructed based on the guidelines specified by the ISO 140-3-1997 specifications (Sean Smith, 1997). The receiver room was completely isolated from the vibration and flanking transmission from the roof as well as from the ground by providing isolation floor and box in box type panels on the side walls. The gaps or leaks between the wall and test specimen were closed by using mastic seal on all the sides. Sound reduction index measurements were conducted using ISO140-3-1997 (Sean Smith, 1997) and ISO 717-1-1997 (Fringuellino and Sean Smith, 1999) specifications. An average sound pressure level was determined at five points both in the source and receiver rooms, and their difference in levels gives the average sound reduction index of the material.

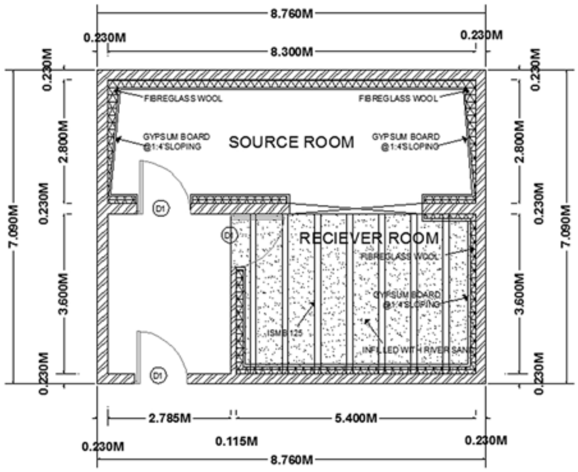

Figure 1.a. Plan of transmission loss suite

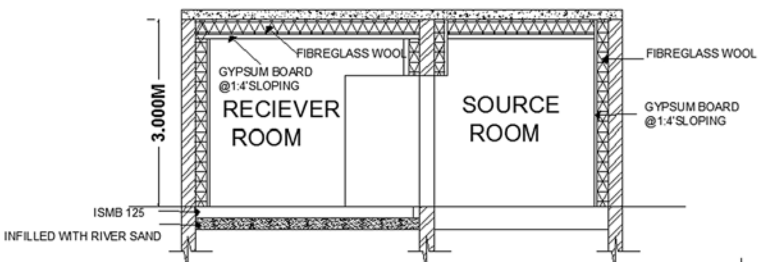

Figure 1.b. Section of transmission loss suite

A difference of stiffness values was seen for the principal directions based on the panel specimen i.e. placement of openings. As a result the critical frequency f_c dip or coincidence valley is broader. Plaster was applied to the specimen to bond the fibers thereby resulting in the increase of air flow resistance leading to improved sound insulation properties (ISO 140-1-1997).

4. Acoustical characteristics of fiber impregnated ferrocement panels

Ferrocement is a kind of composite material in which cement mortar is reinforced with steel meshes (welded mesh and chicken mesh) dispersed throughout the composite resulting in better structural performance than that of its original constituents, viz. cement, sand, coconut shell. The density of the panel is 2 500 kg/m^3 and the modulus of elasticity is 0.3 – 0.5.10^5 N/mm^2. Figure 2 shows the sectional details of the panels fixed at the openings. Figure 3 shows the sound reduction index of ferrocement panel and fiber reinforced ferrocement panels. It is seen that there are dips in 200 Hz and 315 Hz for ferrocement and fiber reinforced panels respectively which are predominant. This is attributed to the resonance that occurs in the low frequency region. Critical frequency dips or coincidence dips occurring at a higher frequency region of 1 250 Hz are due to the thin plate behavior of the panel. At higher frequency and mid frequency regions there is a difference of 10 dB for ferrocement and fibre reinforced ferrocement panels.

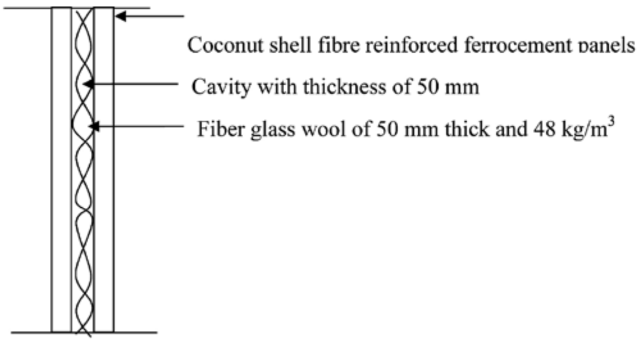

Figure 2. Section details of cavity fiber reinforced ferrocement panel with absorptive material

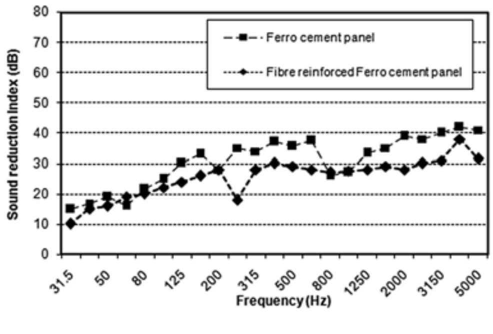

Figure 3. Measured sound reduction index of ferrocement panel ■ and fiber reinforced ferrocement panel (◆)

5. Effect of Cavity between fiber impregnated ferrocement panels

In case of the panel with cavity system, two coconut fiber impregnated ferrocement panels are being separated by a cavity of 50 mm. The overall thickness of the panel system is 90 mm. Figure 4 shows the sound reduction index of the cavity panel. The cavity panel exhibits a sound reduction value of 40 dB. It is seen that the dips are occurring at a low frequency region of 80 Hz, due to the cavity resonance. Critical frequency dips occur at a frequency of 1 600 Hz. The critical frequency occurring at a high frequency is more related to air-cavity coupling that occurs due to the interaction of air in the cavity system. Cavity system exhibits SRI of 35 dB at 500 Hz. The presence of cavity influences the effect of sound transmission, the cavity system absorbs the transmission of energy; thereby the sound reduction index increases with the presence of cavity. Sound reduction index *R* measurements have been conducted inside the cavity. Figure 5 shows the total loss factor of the cavity system. Loss factor is higher at a low frequency and tends towards the internal loss factor value at a high frequency. In this case the loss factor is high when compared to the other two systems because of the presence of the cavity with insulation system. Longitudinal wave speed c_L of the system is 1 875 m/s. It is seen that at high frequencies the loss factor tends towards the measured internal loss factor value of 0.009.

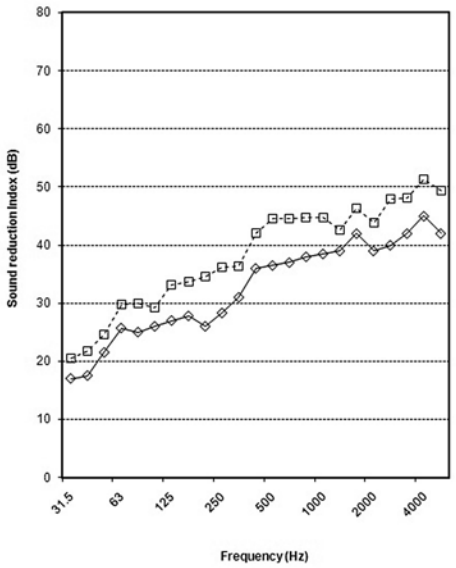

Figure 4. Measured sound reduction index of cavity fiber reinforced ferrocement panels ◇ and cavity with absorptive material ☐

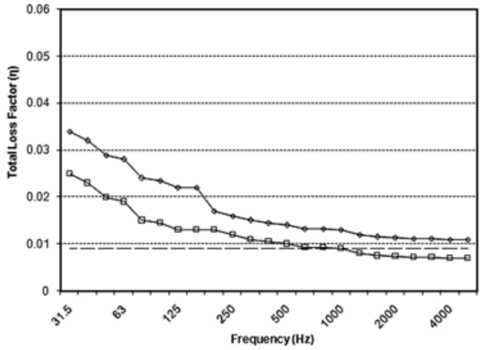

Figure 5. Loss factor of cavity coconut fiber impregnated ferrocement panels ◇ and cavity with absorptive material ☐

6. Effect of Absorptive material in cavity between fiber impregnated Ferro cement panels

In this case the cavity system with two panels with an air gap of 50 mm is constructed and filled in with high-density fiber glass wool foam insulation. Figure 4 shows that the sound reduction index increases more for the panel with cavity insulation than for the other two systems. The sound reduction index of the cavity panel with insulating material is greater than that without insulation by about 10 dB compared to the non-insulated panel. It is seen that the dips occur at 125 Hz in the low frequency region, because of the presence of cavity insulation, the dips are more predominant in the low frequency region, whereas it is not so in the other two cases. At high frequency regions critical frequency dips occur at 1 000 – 2 000 Hz. Figure 5 shows the total loss factor of the panel with cavity insulation. It is seen that the addition of cavity with insulation causes a considerable increase in the loss factor value. This is because of the presence of insulation, which absorbs greater energy through the system thereby the power transmitted through the system gets reduced. This reduction in power transmission is due to the size and thickness of the plate and also due to the air-cavity coupling that plays a major part in energy transmission. Cavity panel with insulation exhibits a SRI of 37 dB at 500 Hz. The longitudinal wave speed of the panel with cavity system is 1800 m/s. The sound reduction index of the panel is 39 dB, which shows a higher sound reduction index than the other panel system.

7. Statistical energy analysis

The SEA model shown in Figure 6 can be used to predict the performance of the cavity fiber impregnated (coconut shell) ferrocement panel with and without absorption. The Coupling Loss Factors (CLF) between the rooms and the walls, i.e., η_{12}, η_{21}, η_{34} and η_{41}, are the same for the solid walls. This can be determined by considering the power flow across the entire cavity area.

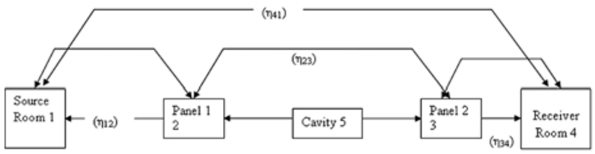

Figure 6. SEA model of ferro cement panel with cavity and absorption

The width of the cavity is 50 mm which is short when compared to the wavelength of the longitudinal wave; hence the cavity can be modeled as a spring. The tie stiffness is determined both theoretically and experimentally. At low frequencies the cavity behaves resiliently and less power is transmitted. Cavity wall performance across the material can be found by considering power balance equation for the subsystems 2, 3, 4 of the SEA model. At high frequencies the coupling between the two leaves is weak and hence the attenuation across the cavity is high. The wall is therefore modeled as two subsystems. At low frequencies however, the two leaves move together and behave as a single wall and are considered to model as one system. The air in the cavity results in additional coupling, for convenience it is easy to predict the coupling by replacing the absorptive material with air stiffness. The air in the cavity is uniformly distributed; an estimate of the coupling can be obtained if it is modeled as being equivalent to the area of the absorptive material acting over the entire area. At high frequency, the effective stiffness of the air is increased and more sound is transmitted across cavity and thin plates. From this the sound reduction index of the material in the cavity with ties was calculated and it is shown in Figure 7.

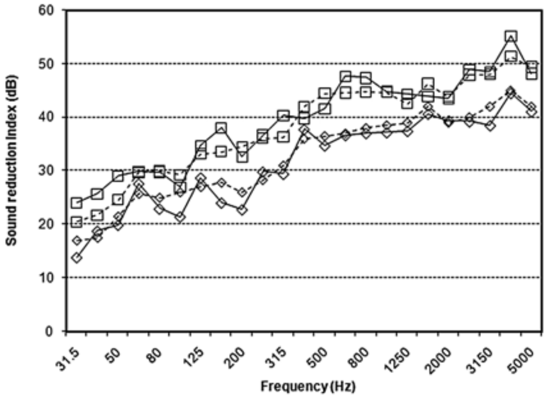

Figure 7. Measured and predicted sound reduction index of cavity fiber reinforced ferrocement panels ☐ and cavity with absorptive material using SEA, experimental - - - - - and SEA ––––––

8. Conclusions

From Figure 4 it is seen that the sound reduction index of the panel with cavity shows prominent dips at low frequency at 100 – 1 250 Hz which are due to the greater energy transfer occurring due to the presence of ties. This in turn matches well with the predicted cavity resonance values which were around 100 Hz. At high frequency regions coincidence dips predominate at 1 250 Hz which again coincides with the predicted value. Critical frequency value of the fiber reinforced ferrocement panel behaves like a thin plate. The measured results all tend to level off at very high frequency due to other transmission paths.

The results are then compared with the theoretical investigation using SEA approach. Figure 7 shows the experimental value coincides with the predicted frequency value of around 1 250 Hz. The agreement between the measured and predicted results improves when the insulation material has been added into the panel.

The sound reduction index increases in the presence of cavity and absorptive material. This is due to the increased mass of the complete section. Sound reduction index also increases at cavity fiber reinforced ferrocement panel with absorptive material. The results show the difference in SRI in the low frequency region which is due to the porosity of absorptive material, where the total loss factor of the panel with material shows a higher loss factor than the cavity fiber reinforced ferrocement panel. Over most of the frequency spectra theoretical values coincide with the measured data.

REFERENCES

[1] Kumar, P. S., Mannan, M. A., Kurian, V. J. and Achyutha, H. (2005), "Effect of Crushed Sandstone Sand on the Properties of High Performance Concrete", Journal of Civil Engineering Research and Practice 2, 1-11.

[2] Mannan, M. A., Kumar, P. S., Kurian, V. J. and Achuytha, H. (2007), "Investigation on the flexural behaviour of high performance reinforced concrete beams", Building and Environment, 42, 2622-2629.

[3] Macadam, J. A. (1976), "The Measurement of Sound Radiation from Room Surfaces in Light Weight Buildings", Applied Acoustics 9, 103-118.

[4] Craik, R. J. M. (1998), "The consequences of lightweight buildings on sound transmission", Building Services Engineering Research Technology 19, B1-4.

[5] Sean Smith, R. (1997), "Sound Transmission through Lightweight Parallel Plates", Ph.D. thesis, Heriot-Watt University, Edinburgh, UK.

[6] Fringuellino, M. and Sean Smith, R. (1999), "Sound Transmission through Hollow Blocks", Journal of Building Acoustics 6, 211-224.

[7] ISO 140-1-1997, Measurement of sound insulation in buildings and building elements-Part 1: Requirements of laboratories.

[8] ISO 140-3-1997, Measurement of sound insulation in buildings and building elements-Part 3: laboratory measurements of airborne sound insulation of building elements.

[9] ISO 717-1-1997, Rating of sound insulation in building and of building elements-Part1- Airborne sound insulation.

[10] Craik, R. J. M. and Wong, L. J. (1980), "The measurement of material properties in buildings", Proc. Institute of Acoustics Spring Conference, London, UK, 77-80.

[11] Craik, R. J. M. (1996), Sound Transmission through Buildings using Statistical Energy Analysis, Gower Pub., UK.

[12] Lyon, R. H. and Dejong, R. (1995), Theory and Applications of Statistical Energy Analysis, Butterswoth-Heinmann Pub., New York.

[13] Craik, R. J. M. and Steel, J. A. (1989), "The effect of workmanship of sound transmission through buildings: Part1 – Airborne sound", Applied Acoustics 27, 57-63.

[14] Cremer, L., Heckl, M. and Ungar, E. E. (1987), Structure Borne Sound, Springer-Verlag Pub., Berlin.

[15] Ljunggren, S. (1991), "Airborne sound insulation of thick walls", Journal of Acoustical Society of America, 89, 2338-2345.

[16] Rindel, J. H. (1994), "Dispersion and absorption of structure-borne sound in acoustically thick plates", Applied Acoustics 41, 97-111.

[17] Craik, R. J. M., (1981), "Damping of building structures", Applied Acoustics 14, 347-359.

[18] Craik, R. J. M. and Barry, P. J. (1992), "The internal damping of building materials", Applied Acoustics 35, 139-148.