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Study on acoustic properties of natural fiber reinforced light weight concrete

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ABSTRACT

Fibers and foams are commonly used in commercial solutions in acoustic applications because of their excellent sound absorption coefficient at high frequencies [1, 2]. The present study focuses on improving sound absorption property of lightweight concrete by adding coconut fibers in different proportions (0.5%, 1%, and 1.5%) in a concrete where fine aggregate is replaced by 7% perlite. Gypsum is added to replace 10% cement to make the concrete lightweight and also to perform as a good sound absorber. A foaming agent is also added to improve the porous property of the concrete [2]. Acoustic absorption coefficient is determined using impedance tube method-ISO 10534- 1:1996 [7]. The responses from the tests performed are compared and the results are analyzed. The results shows that addition of fiber increases sound absorption property and also addition of perlite and gypsum which makes the concrete lightweight also have a significant impact.

Keywords: *Sound absorption coefficient, perlite, coconut fiber, foaming agent, impedance tube.*

1. INTRODUCTION

Due to scientific and technological developments, people enjoy great progresses in various fields such as industry, transportation and construction. But along with the benefits, people also have to face increasing environmental pollution along with economic development. Noise pollution is a great concern nowadays and it affects urban comfort and people's everyday life. Due to this problem, more and more researchers have begun to find a solution for it. Sound absorbing materials are a great choice to relieve noise.

Sound absorbing materials uses porous property in them for performing the absorbing function. 'Sound Absorption Coefficient' is used to evaluate the sound absorption efficiency of materials. Its value ranges from 0 to 1. Zero represents total absorption and one represents total reflection. The average sound absorption performance of a material is described by a value called 'Noise Reduction Coefficient' which ranges from 0 to 1.

Sound absorption is affected by factors such as density, porosity, thickness and aggregate size *[5]*. Sound absorption coefficient is measured using two methods: Impedance tube method-ISO 10534-1:1996 and Reverberation room method – ISO 354:2003. Impedance tube method is used here.

2. MATERIALS AND METHODS

2.1. Materials

The materials used in this study for sound absorbing concrete are ordinary Portland cement and gypsum as binders, M-sand and perlite powder as fine aggregates, perlite granules as coarse aggregate, coconut fiber, and foaming agent to provide porous nature, super plasticizer and water.

Gypsum and Perlite are lightweight material which reduces the density of the concrete and also acts as good sound absorbers. The specific gravity of gypsum is less than cement; hence gypsum reduces the density of concrete. Since generally fibers contribute to sound absorption, fiber is added. Coconut fiber is chosen because of its good sound absorption property for frequency approximately 2500–3100 Hz and good tensile strength *[1]*. To increase porosity of concrete, foaming agent is added *[4, 2]*. By adding foaming agent, we can also obtain light weight property of concrete. Polyethylene glycol foam is used in this study. To improve workability, super plasticizer is added. Conplast sp430 is used.

Table-1: Chemical compositions of OPC-53

CHEMICALS	**OPC 53**
SiO_2	66.67
CaO	18.9
Al_2O_3	4.5
Fe_2O_3	4.9
MgO	2.5
K_2O	0.87
NaO_2	0.43
SO_3	0.12

The chemical composition of cement is given in table 1. The properties of coconut fiber are given in table 2.

Table- 2: Properties of coconut fiber

Diameter of the fiber	0.1mm-0.406mm
Tensile strength of the fiber	150 MPa
Elongation at break %	10% to 25%
Specific Gravity	1.12-1.15
Fiber length	50mm -110mm

Table-3: Designations of mixtures

Mix designation	**Composition of mixes**
M1	Cement + gypsum (10% of cement) + m-sand + foaming agent
M2	Cement + gypsum (10% of cement) + m-sand + foaming agent + perlite powder (4% m-sand)+ perlite granules (3% m-sand)
M3	Cement + gypsum (10% of cement) + m-sand + perlite powder (4% m-sand) + perlite granules (3% m-sand) + foaming agent + fiber (0.5%)
M4	Cement + gypsum (10% of cement) + m-sand + perlite powder (4% m-sand) + perlite granules (3% m-sand) + foaming agent + fiber (1%)
M5	Cement + gypsum (10% of cement) + m-sand + perlite powder (4% m-sand) + perlite granules + foaming agent (3% m-sand) + fiber (1.5%)

2.2. Methods

2.2.1. Mixing

The five mixtures, mentioned in Table 3, were prepared according to the proportions given to obtain M15 grade of concrete as per IS 10262-2009 *[6]*. Cement, gypsum, perlite powder and perlite granules are mixed thoroughly in dry state. Fibers are pre-wetted and added. Foaming agent is mixed with water and beated to produce foam and foam is added. Then, water was added and the ingredients were further mixed thoroughly by a mechanical mixer until the mass attained a uniform consistency.

2.2.2. Preparation of Samples

For mechanical tests, cubes of standard sizes 150mm*150mm*150mm and cylinders of 150mm diameter and 300mm length are prepared. For impedance tube test, two sets of samples are prepared. The samples are disc-shaped: one set of samples having disc of diameter 99mm and length 30mm as shown in fig.1 and another set of samples having disc of diameter 29mm and length 30mm as shown in fig.2.

Figure-1: Specimen of diameter 29mm

Figure-2: Specimen of diameter 99mm

2.2.3. Testing

The mechanical tests done are compressive strength test, split tensile strength and durability tests done are water absorption and density test to ensure lightweight property. Then, impedance tube test is done to find sound absorption coefficient which is done according to ISO 10534-1:1996 *[7]*. Since curing has no effect on sound absorption property, the specimens for impedance tube test are cured for 3 days *[1]*.

2.2.4. Acoustic Properties

2.2.4.1. Sound Absorption Coefficient: Sound Absorption Coefficient is defined as the ratio of absorbed energy to incident energy. It is measured using impedance tube test according to ISO 10534-1:1996.

2.2.4.2. Noise Reduction Coefficient

The noise reduction coefficient describes the average sound absorption performance of a material. Its value ranges from 0 to 1 *[3]*.

2.2.5. MATLAB Analysis

In this study, FFT analysis is done using MATLAB code for the initial sound wave and wave after passing through the sample used in Impedance Test experiment to find sound absorption coefficient. Through FFT analysis, frequency domain can be obtained from time domain and thus frequency Vs magnitude graph can be obtained for the two sound waves. From the graph obtained, analysis can be made.

2.2.5.1. Output: The output for code 1 is as below:

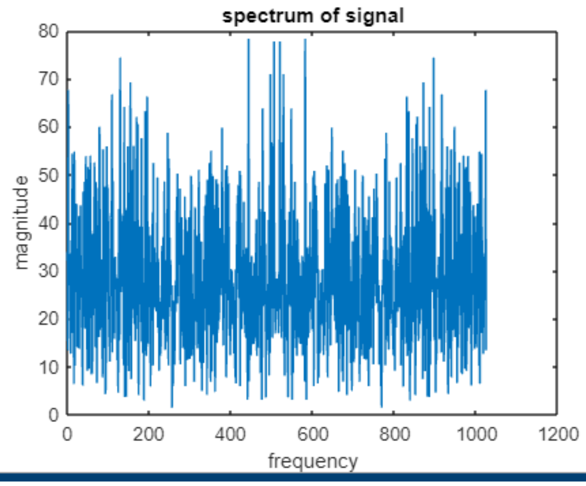

Figure-3: Spectrum of initial Sound wave before passing through the sample

The output for code 2 is as below:

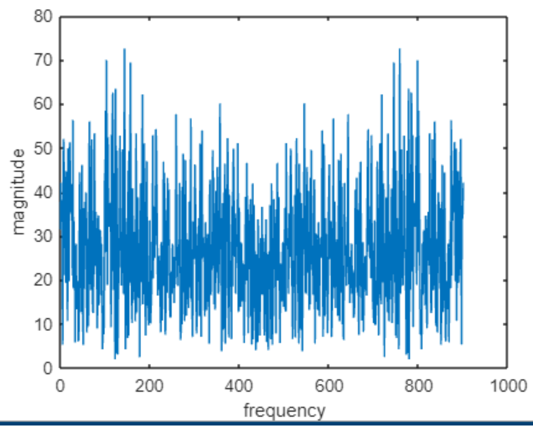

Figure-4: Spectrum of Sound wave after passing through the sample

2.2.5.2. Summary

From the two graphs obtained in fig.3 and fig.4, it is observed that magnitude of frequency of wave after passing through the sample is lesser than the magnitude of frequency of initial wave. It shows that the energy of first wave is higher than the second wave. Thus, some of the energy got absorbed by the sample. It clearly shows that the sound absorption coefficient value is less than 1. Thus, finally, it depicts that sound absorption happens through the sample and the sample is a sound absorbing.

3. RESULTS AND DISCUSSION

3.1. Mechanical Properties

3.1.1. Compressive strength test

Five different proportions of Concrete cubes are casted. The 7^{th} and 28^{th} days cube compressive strength test results are shown in table 4 respectively.

Table-4: Compressive Strength Test Results

Mix	Description	7^{th} day Compressive Strength (MPa)	28^{th} day Compressive Strength (MPa)
M1	Concrete without perlite	9.6	14.72
M2	Concrete with 7% perlite replacement of M sand	7.91	12.2
M3	Concrete with 0.5% fibers in addition to 7% perlite	7	10.89
M4	Concrete with 1% fibers in addition to 7% Perlite	6.9	10.32
M5	Concrete with 1.5% fibers in addition to 7% perlite	6.13	9.69

The experimental results are compared as shown in the figure 5.

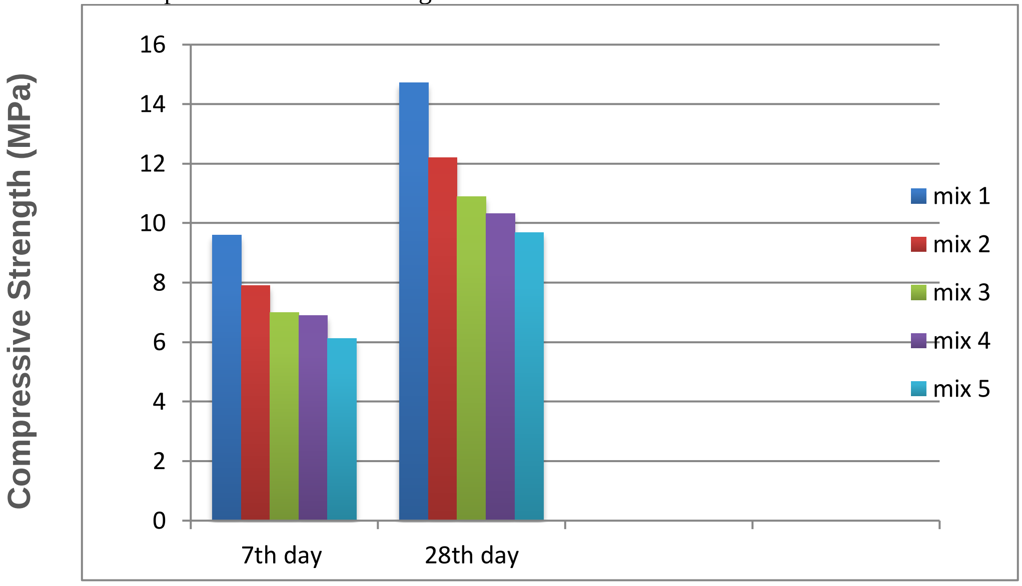

Figure-5: Comparison of Compressive Strength Test Results

In this study, the target compressive strength for M15 grade of Concrete is found to be 20.775MPa. From the results, it is observed that the 28th day compressive strength for Concrete without perlite is 14.72MPa which is less than the target compressive strength. The maximum strength obtained from all mixes is 14.72MPa. Thus, the mix design cannot achieve its target strength. When perlite is added to replace 7% M sand, the compressive strength reduces further. And, when fibers are added, compressive strength further reduces gradually with increase in fiber content. Thus, only M10 grade of concrete is able to be achieved.

3.1.2. Split Tensile strength test

Five different proportions of Concrete cylinders are casted. The 7th and 28th days split tensile strength test results are shown in table 5 respectively.

Table-5: Split tensile strength Test Results

Mix	Description	7th day Compressive Strength (MPa)	28th day Compressive Strength (MPa)
M1	Concrete without perlite	0.76	1.2
M2	Concrete with 7% perlite replacement of M-sand	0.71	0.98
M3	Concrete with 0.5% fibers in addition to 7% perlite	0.76	1.19
M4	Concrete with 1% fibers in addition to 7% perlite	0.89	1.34
M5	Concrete with 1.5% fibers in addition to 7% perlite	1.01	1.47

The experimental results are compared as shown in the figure 6.

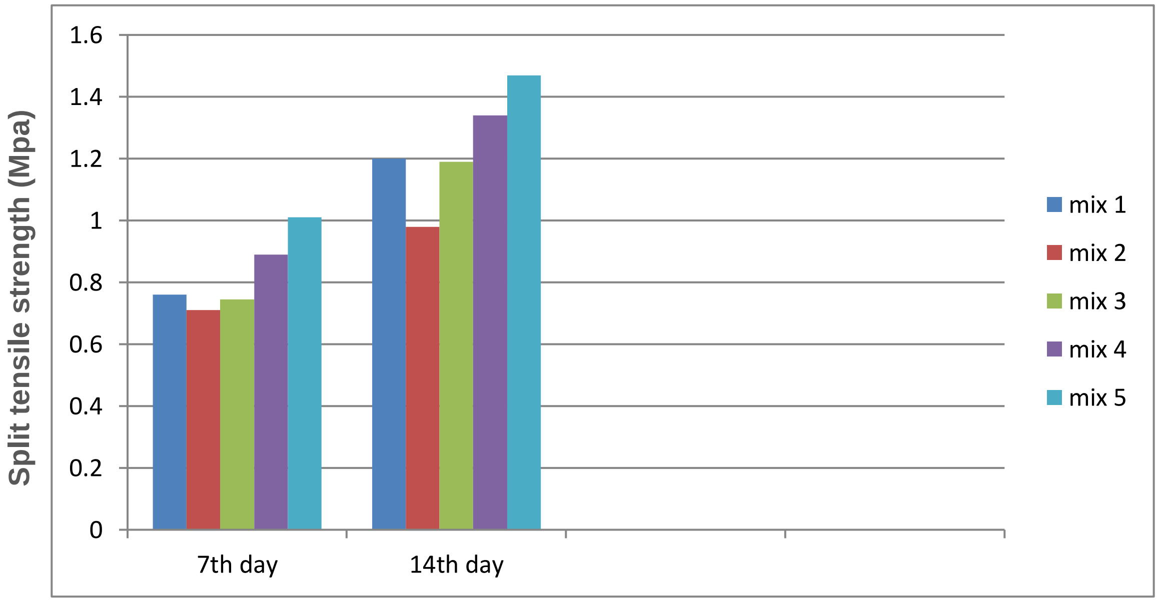

Figure-6: Comparison of Split tensile strength Test Results

The formula to calculate the split tensile strength is, Split tensile strength = 0.7 $\sqrt{f_{ck}}$, where f_{ck} is the characteristic compressive strength of concrete. Based on the formula, the split tensile strength that has to be achieved for Concrete is 2.71MPa.

In Concrete without perlite, the 28th day split tensile strength achieved is 1.2 MPa which is less than the target split tensile strength. When 7% perlite is added to the concrete by replacing M-sand, a split tensile strength value of 0.98MPa is obtained which is lesser than the concrete without perlite. Coconut fibers are added to increase the split tensile strength. When 0.5% of fibers by total weight of concrete are added, the 28th day split tensile strength increased to 1.19MPa. Further when fiber percentage is increased to 1% and 1.5%, correspondingly the split tensile strength increased to 1.34MPa and 1.47MPa respectively. But, still the attained strength is less than target strength. It is concluded that the addition of fibers improves the split tensile strength of concrete.

3.2. Density test

Since it is a lightweight concrete, density must be checked to ensure its lightweight property. Five different proportions of Concrete cubes are cast. The density test results are shown in table 6 below.

Table-6: Density Test Results

Mix	Mix proportions	Density(kg/m^3)
M1	Concrete without perlite	**1777.78**
M2	Concrete with 7% perlite replacement of M-sand	**1693.24**
M3	Concrete with 0.5% fibers in addition to 7% perlite	**1698.5**
M4	Concrete with 1% fibers in addition to 7% perlite	**1695.3**
M5	Concrete with 1.5% fibers in addition to 7% perlite	**1701.3**

In general, density of lightweight concrete ranges from 500-1850kg/m^3. From the above table, it is seen the maximum density obtained from mix 1 which is 1777.78kg/m^3. The highest value obtained is within the range of density of lightweight concrete. Thus, concrete produced in all mixes comes under lightweight category.

3.3. Water absorption test

Since coconut fiber is a water absorbing material, the concrete is checked for water absorption to conform whether the concrete lies within durability standards. Five different proportions of Concrete cubes are cast. The results of water absorption test results are shown in table 7 below.

Table-7: Water Absorption Test Results

Mix	Mix proportions	Water absorption (%)
M1	Concrete without perlite	2.57
M2	Concrete with 7% perlite replacement of M-sand	3.2
M3	Concrete with 0.5% fibers in addition to 7% perlite	3.29
M4	Concrete with 1% fibers in addition to 7% perlite	3.09
M5	Concrete with 1.5% fibers in addition to 7% perlite	3.19

In general, water absorption should be less than 3% according to BS 6349. Here, mix1 satisfies the condition. Other mixes have a value exceeding 3%. However, mix M4 can be considered ideal since it is only a marginal difference.

3.4 Impedance Tube Test

Five different proportions of Concrete cubes are casted. The test results for various frequencies are shown in table 8 respectively. The experimental results are compared as shown in the figure 7.

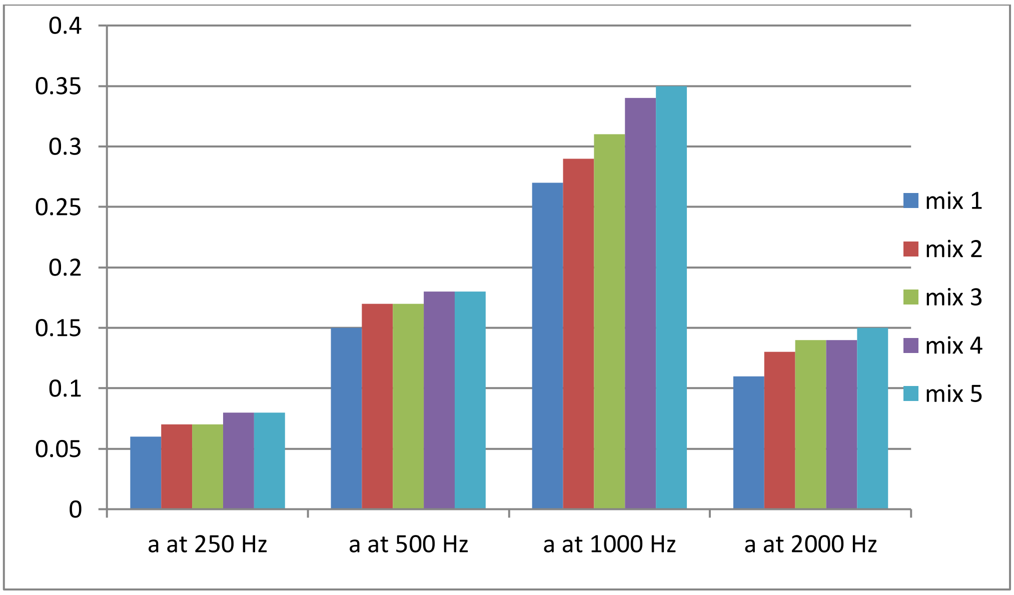

Figure-7: Comparison of Impedance tube test Results

Table-8: Impedance Tube Results

Mix	Description	Sound absorption Coefficient (at 250 Hz)	Sound absorption Coefficient (at 500 Hz)	Sound absorption Coefficient (at 1000 Hz)	Sound absorption Coefficient (at 2000 Hz)
M1	Concrete without perlite	0.06	0.15	0.27	0.11
M2	Concrete with 7% perlite replacement of M-sand	0.07	0.17	0.29	0.13
M3	Concrete with 0.5% fibers in addition to 7% perlite	0.07	0.17	0.31	0.14
M4	Concrete with 1% fibers in addition to 7% perlite	0.08	0.18	0.34	0.14
M5	Concrete with 1.5% fibers in addition to 7% perlite	0.08	0.18	0.35	0.15

Mix M5 has a sound absorption coefficient of 0.35 at 1000Hz which is the maximum amongst the five proportions. Sound absorption coefficient of Concrete without perlite is 0.27 and concrete with perlite is 0.29. Thus, addition of perlite improves sound absorption. When 0.5% of coconut fibers by total weight of concrete is added, the value increases to 0.31. When the addition of fibers is increased to 1% and 1.5%, sound absorption coefficient further increases to 0.34 and 0.35 respectively. Concrete without perlite has the least sound absorption coefficient.

According to classification of sound absorption materials from fig.8, concrete from mix 1 and mix 2 falls under class E. And, concrete from mix 3, mix 4 and mix 5 falls under class D.

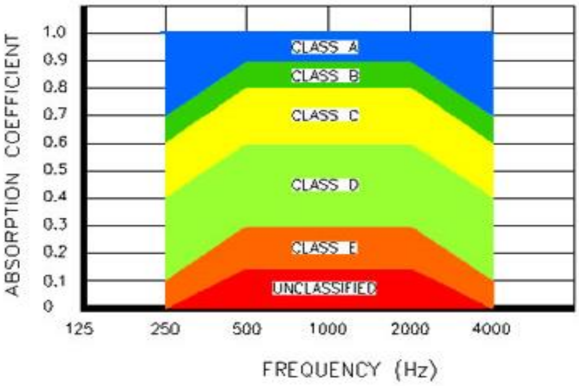

Figure-8: Classification of Sound Absorbing Materials according to ISO 11654

4. CONCLUSION

The results of the compressive strength test, split tensile strength test and impedance tube test for the mixes M1, M2, M3, M4 and M5 are compared and the following conclusions are arrived.

- Comparing the results of impedance tube test for the mixes M1, M2, M3, M4 and M5, the mix M5 has the maximum value and M1 has the minimum value.
- Comparing the results of compressive strength test for the mixes M1, M2, M3, M4 and M5, the mix M1 has the maximum value and M5 has the minimum value.
- Comparing the results of split tensile strength test for the mixes M1, M2, M3, M4 and M5, the mix M5 has the maximum value and M2 has the minimum value.
- As a whole, the mix M4 is found to be the optimum mix, since it meets the requirements of the compressive strength test, flexural strength test and impedance tube test more than other mixes.
- Since, attaining sound absorption coefficient is the main aim, mix M4 is chosen since it comes under class D under classification of sound absorbing materials and also, strength properties is also not much less than other mixes.

5. REFERENCES

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