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Determination of the Sound Absorption Coefficient and Young's Modulus of Concrete withAgricultural By-Products

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Abstract

This study determined the effects of admixtures such as the locally produced and abundant agricultural by-products — corn husks, coconut coir, and rice hulls — on the sound absorption characteristics and Young's modulus of concrete. The sound absorption coefficient was measured using the two-microphone impedance tube for the transfer function method while an improvised center-point loading procedure was used in determining the Young's moduli of the concrete samples. There were four samples used: S1 (concrete), S2 (concrete with corn husks), S3 (concrete with coconut coir), and S4 (concrete with rice hulls). The results showed that each absorption profile for each sample had two pronounced absorption peaks. The effect of adding the admixtures shifted the first absorption peaks to a higher frequency. It also broadened the absorption band of concrete. However, on the second peak, the absorption peaks decreased and shifted slightly to a lower frequency relative to S1. The emergence of the second peak was due to the air space created by the uncontrolled corrugation of the other surface of the cylindrical samples. Among the three admixtures, S4 was the least absorptive with $\alpha = 0.80$, compared to S2 ($\alpha = 0.96$) and S3 ($\alpha = 0.94$).

Keywords: admixture, sound absorption coefficient, Young's modulus, concrete, school acoustics, Philippines.

INTRODUCTION

Good acoustical qualities are essential in classrooms and other learning spaces in which speech communication is an important part of the learning process. Excessive background noise or reverberation in such spaces interferes with speech communication and thus presents an acoustical barrier to learning. With good classroom acoustics, learning is easier, deeper, more sustained, and more convenient. Teaching should be more effective and less stressful with good acoustical characteristics in the classroom. There can be more verbal interaction and less repetition between teacher and students when spoken words are clearly understood. Although all those in the classroom, including teachers and adult learners, will benefit, special beneficiaries are young children and persons with hearing, language, speech, attention deficit, or learning disabilities (Acoustical Performance Criteria, Design Requirements, and Guidelines for Schools 2002).

Many educators feel it is important to improve acoustics in classrooms used by children with hearing problems but unnecessary to do so in those used by students with normal hearing. Many populations of students with "normal hearing" also benefit from better classroom acoustics. These include students with learning disabilities, those with auditory processing problems, and those (like most Filipinos) for whom English is a second language. Often, such students are not placed in separate classrooms with enhanced acoustics but are mainstreamed with other students. Given these considerations, it is clear that a wide range of students benefits from improved classroom acoustics (Seep et al. 2000).

Speaking and listening are the primary communication modes in most educational settings. Unfortunately, many learning spaces have excessive noise (any unwanted sound inside or outside of the room) and reverberation time (persistence of sound after the source itself stops). All students and teachers are negatively affected by noise and reverberation, but young students, English language learners, and students and teachers with hearing, language, or learning problems may be at a greater disadvantage. The acoustical properties of classrooms are often the “forgotten variables” in ensuring students' academic success, particularly for students with unique communication or educational needs (Crum and Matkin 1976).

Why should problems in classroom acoustics be endemic when solutions are not prohibitively expensive? The main reason is not lack of funds but lack of awareness of the problem and its solutions. For these solutions to happen, school planners and architects must begin the design process with classroom acoustics in mind. The best way to solve acoustical problems is to prevent them beforehand, not correct them after their implementation. During the design process, acoustics problems can usually be avoided with a bit of forethought and a different arrangement of the same building materials. Renovation of poorly designed classrooms is much more expensive. Even then, the cost of renovation is small compared to the social costs of poor classroom acoustics that impair the learning of millions of children (Seep et al. 2000).

Cutnell and Johnson (2007) describe sound as a longitudinal wave created by a vibrating object. It can be created or transmitted only in a medium, such as gas, liquid, or solid. The sound absorption coefficient of an object, according to Everest (1994), is a measure of the efficiency of its surface or material in absorbing sound.

Concrete is a common material found in most typical Filipino houses and buildings, especially school classrooms. It is made up of aggregates, cement, and water. According to Tiwari et al. (2003), many studies have been made to enhance the sound-absorbing property of concrete. In road constructions, for example, several studies have been made to reduce tire-pavement interaction noise. One way of improving the quality of concrete is through the addition of admixtures.

Admixtures are materials other than water, aggregate, or hydraulic cement which are used as ingredients of concrete and which are added to the batch immediately before or during the mixing operation (Nawy 2001). Addition of fiber to concrete makes it tough and fatigue-resistant. Such type of admixtures is used extensively in important engineering projects. Fiber reinforcement of cement and concrete is not a new concept since people have been using reinforcements like straw in bricks and hair in mortar for a long time (Kachchhi 2010).

In this study, the researcher is interested in determining the effects of admixtures, such as the locally produced and abundant agricultural by-products (corn husk, coconut coir, and rice hulls) on the sound absorption characteristics and Young's modulus of concrete. The sound absorption coefficient will be measured using the two-microphone impedance tube for the transfer function method (Salumbides & van Engelen 2004) while an improvised center-point loading procedure will be used for determining the Young's moduli of the concrete samples.

Objectives

The goal of this study was to compare the sound absorption coefficients of concrete samples added with corn husk, coconut coir, and rice hulls.

Specifically, it aimed to determine the sound absorption profile of different concrete samples added with corn husk, coconut coir, and rice hulls; compare the sound absorption profile of each sample to a concrete sample with no admixture; and determine the Young's moduli of the different concrete samples added with either corn husk, coconut coir, or rice hulls.

MATERIALS AND METHODS

I. Preparation of Concrete Samples

A. Construction of Cylindrical and Rectangular Molds

Two types of molds were made. Eight cylindrical molds were made for the samples used in the sound absorption measurement. These were made according to the allowable size that could fit the impedance tube. The impedance tube measured 6.00 cm in inner diameter. Each mold had a height of 3.00 cm and was cut from a PVC pipe of 5.75 cm in diameter.

Six rectangular wooden molds were made, each with dimensions of 30.00 cm by 2.00 cm by 3.00 cm. The sides and the bases of the rectangular molds were coated with adhesive tape. This procedure was done to ensure that the concrete mixture would not stick to the wood.

Figure 1. Cylindrical molds.

B. Preparation of Admixtures

Admixtures were obtained, each with a mass of 1.00 kg. These were washed thoroughly, and only the needed parts were used. After the admixtures had been washed, each admixture was placed in a kettle half-filled with water. Each mixture was boiled using an electric stove. The excess water was removed, and only the admixtures were taken after boiling. The boiled admixtures were placed in three separate trays. They were then sun-dried for two days. Each was pulverized using a grinder until a powder-like consistency was obtained.

Figure 2. Washing of admixtures.

Figure 3. Boiling of admixtures.

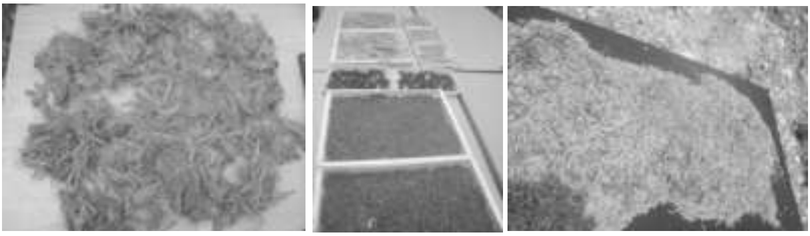

Figure 4. Drying of admixtures.

Figure 5. Pulverized admixtures.

C. Mixing of Ingredients for Concrete

The dry ingredients (Portland cement, fine aggregate, and coarse aggregate) for concrete were obtained, each having a mass of 2.00 kg.

For the cylindrical samples, four samples of concrete were made, each with a volume of 96.0 mL. Sample 1, which was the control sample, was made up of concrete with no admixture. Sample 2 consisted of concrete and corn husk powder. Sample 3 was composed of concrete and coconut coir powder. Sample 4 was made up of concrete and rice hull powder. Each sample consisted of 24.0 mL concrete, 32.0 mL fine aggregate, and 40.0 mL coarse aggregate. For the samples with admixtures, 20.0 mL of admixture was added to each sample.

For the rectangular samples, three samples of concrete were made, each with a volume of 144.0 mL. Sample 2 consisted of concrete and corn husk powder. Sample 3 was made up of concrete and coconut coir powder. Sample 4 was composed of concrete and rice hull powder. Each sample consisted of 36.0 mL concrete, 48.0 mL fine aggregate, and 60.0 mL coarse aggregate. In each sample, 30.0 mL of admixture was added.

The dry ingredients, except the admixture, were combined in a mixing bowl. Water was gradually added to the mixture while mixing until the desired consistency was obtained. The admixtures were added to each sample after the concrete mixture was made, following the specified amounts by volume.

After the mixing process, the different mixtures were put into their respective molds (cylindrical and rectangular). The samples were allowed to dry for a curing period of seven days. Two other sets of concrete samples, for both cylindrical and rectangular molds, were made using the same volume method. The same sets of procedure that were discussed were employed for these sets.

Table 1. Summary of Proportions

	Volume (mL)		**Percentage by Volume (concrete without admixture)**	
	Cylindrical	Rectangular	Cylindrical	Rectangular
Cement	24.0	36.0	0.250	0.250
Aggregate	72.0	108.0	0.750	0.750
Fine	32.0	48.0	0.333	0.333
Coarse	40.0	60.0	0.420	0.420
Admixture	20.0	30.0	0.210 relative to the concrete mixture	0.210 relative to the concrete mixture
Total	96.0	144.0	100.	100.

II. Preparation of the Two-Microphone Impedance Tube

The transfer-function method or the two-microphone method was used in this study. At one end of a plane-wave tube was the compression driver, which generated the incident and reflected waves. The sample was mounted at the other end. At certain distances near the specimen and along the impedance tube, two microphones were mounted in the duct wall to measure the incident and reflected waves.

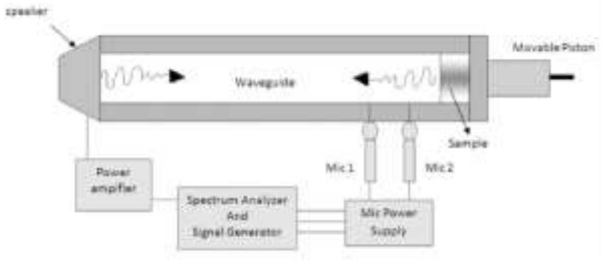

Figure 6. Two-microphone impedance tube.

The impedance tube was made of aluminum. It was 110.00 cm in length and 6.00 cm in inner diameter. A speaker of diameter 7.00 cm was interfaced to a computer using the sound card while the microphones were connected to the NI-6014 multichannel data acquisition card. The transfer function from the two microphones was measured by Fourier transformation. A LabView program using FFT algorithms was employed, and the transfer function complex reflection coefficients were obtained. From that, the LabView program calculated the absorption coefficient for all the frequencies.

III. Preparation of the Young's Modulus Setup

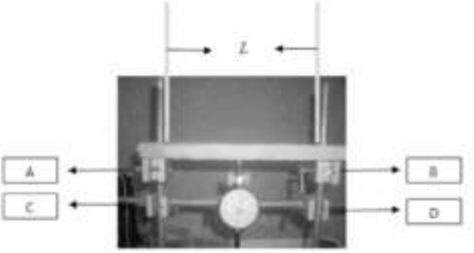

Figure 7. Setup for the measurement of Young's modulus.

The setup in Figure 7 was used in the measurement of Young's modulus, showing a concrete bar that was supported at two points, A and B. The width a and thickness b of the bar were measured. The effective length L of the bar was measured in the manner shown in Figure 7.

A dial gauge holder was placed at the center of the iron rod, and the initial reading was adjusted to zero. A 250-g metal piece was carefully placed at the center of the bar, and the resultant bending Δy of the bar was measured. Loads of 250 g each were continuously added, one at a time, until a total of 1500 g was reached.

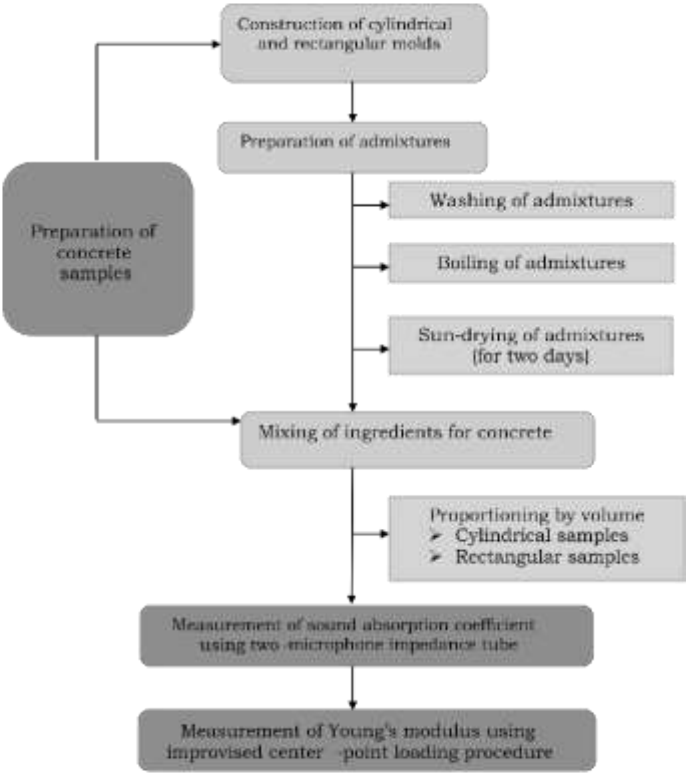

Figure 8. Schematic diagram of methodology.

RESULTS AND DISCUSSION

A. Sound Absorption Characteristics of Concrete

Absorption profiles of four concrete samples were determined: concrete with no admixture as the control sample (S1), concrete with corn husk (S2), concrete with coconut coir (S3), and concrete with rice hulls (S4). Before any actual measurements with these samples were done, a standard fiberglass sample of known absorption profile was used to check the consistency and workability of the two-microphone impedance tube.

As for each of the actual samples investigated, the absorption coefficients as a function of frequency are shown in Figure 9. Exhibited in the figure is a comparison of the absorption profiles of samples S1, S2, S3, and S4. Each absorption profile was an average of fifteen measurement trials. Since the range of frequency of measurement was limited to the length of the tube and the spacing between the two microphones, the reliable data was limited within the range of 200–3500 Hz (Salumbides & van Engelen 2004).

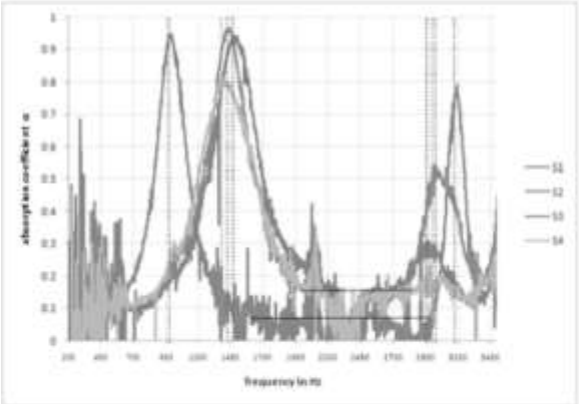

Figure 9. Sound absorption profile of the samples.

It could be observed in Figure 9 that each sound absorption profile had two pronounced absorption peaks at two different bandwidths, one in the low-frequency range and other in the high-frequency range. The values of the peak absorption coefficients that occurred at specific frequencies are presented in Table 2. The first absorption peak of the control sample, S1, which occurred at a lower frequency, was around 94 percent. As compared to the three other samples, results showed that the effect of the admixtures had shifted the first absorption peaks to a higher frequency range. The peaks for S2, S3, and S4 were relatively within the same frequency range. According to Rossing et al. (2002), porous materials absorb well at high frequency. The addition of fiber as admixture enhanced the material's porosity. However, among the three samples with admixtures, S4 (with rice hulls) had the least peak absorption at only about 80 percent compared to S2 (with corn husk) which was about 96 percent (highest) and S3 (with coconut coir) at 94 percent. While the absorption peak shifted to a higher frequency, it also broadened the band where the first absorption peak occurred. This occurrence could be explained by the characteristics of sound absorbers. With S1, the absorption peak occurred between the frequency range of 450–1300 Hz with the full width at half maximum (FWHM) of 312 Hz while S2, S3, and S4 had 438 Hz, 474 Hz, and 546 Hz, respectively. The peaks were found within the frequency range of 450–2300 Hz. It is also interesting to note that the low absorption response of the control sample, S1, which was between 1300–3100 Hz, had narrowed to between 2300–2700 Hz (before the second peak occurred). Furthermore, the absorption coefficients in this frequency band had relatively increased from an average absorption of about 5 percent to an average higher than 10 percent.

Table 2. The Absorption Peaks of the Samples with their Corresponding Frequencies

	First Peak	**Frequency**	**FWHM**	**Second Peak**	**Frequency**
S1 (control)	0.94	998 Hz	312 Hz	0.79	3186 Hz
S2 (corn husk)	0.96	1438 Hz	438 Hz	0.54	3026 Hz
S3 (coconut coir)	0.94	1496 Hz	474 Hz	0.30	2996 Hz
S4 (rice hulls)	0.80	1408 Hz	546 Hz	0.21	2982 Hz

About the second absorption peak, a broadening of the absorption band was also observed; however, the absorption peaks decreased and shifted slightly toward the lower frequency relative to the absorption peak of the control sample. It is believed that the emergence of the second absorption peak may be attributed to a small air space (due to the rough, corrugated back surface of the sample) between the surface of the back of the sample and the hard termination (piston) of the impedance tube. In the study of Salumbides and van Engelen (2004), they investigated the effect of air space between the sample and the hard termination of the tube. They found out that the emergence of the short peaks in the higher frequency range was an effect of the presence of the air space. According to the study, the second peak was caused by the creation of an air cavity whose resonance contributed to the additional absorption of the incident acoustic wave. In the case of this study, however, the texture of the two side surfaces of the samples were not identical (one side was smooth, and the other side was rough). The existence of the rough, corrugated back surface was limited by the production of the samples used. It was difficult to make both surfaces smooth. The researchers chose the smooth surface to be the absorbing surface (side exposed to the sound source), considering the practical application of the concrete. Thus, the observation and the believed reason as for the case of the samples needed further investigation, which was beyond the scope of this study.

The sound absorption profile of rigid fiberglass was initially tested to check the workability of the impedance tube used. Two notable characteristics were observed from the graph: a very wide absorption band and an absorption peak in the same frequency range with the absorption peaks of the sample. According to Winer (2008), fiberglass is the most effective sound absorber for the midrange and high frequencies. Considering the wide absorption bandwidth of the samples with admixture as compared to that of the control sample, results implied that S2 (concrete with corn husk) was the best sound absorber. Furthermore, results showed that the samples with admixtures were better sound absorbers than the concrete sample with no admixture.

As a possible application to classroom usage, the concrete samples with admixtures are better than concrete in absorbing sound and reducing reverberation. The human voice has frequency ranges from about 60 to 7000 Hz. This range coincided with the effective absorption frequency range of the samples.

B. Young's Modulus E of Concrete with Admixtures

In this part of the study, the researchers determined the Young's modulus E of elasticity of S2 (concrete with corn husk), S3 (concrete with coconut coir), and S4 (concrete with rice hulls). For each sample, there were three subsamples (e.g., for S2 — concrete with corn husk — the subsamples were S2a, S2b, and S2c). Each subsample was tested for Young's modulus using the center-point loading method. In this method, the subsample was mounted on the center-point loading setup. The average measured values of L, a, and b were used for each sample. The mass intervals upon which the values of the load force F were based were also held constant. Each set of the corresponding values of elongation $\Delta y_{\text{increasing}}$ per load force F was recorded and tabulated, and plots of $\Delta y_{\text{increasing}}$ as a function of F for each subsample were done as shown in Figures 10, 11, and 12. The corresponding E values were computed from the slope of each linear fit, and the corresponding absolute error E values were determined by linear regression and error propagation (for details, see Appendix E, F, and G) based from Equation 6. The equation suggested direct relation between $\Delta y_{\text{increasing}}$ and F; however, we could observe from Figures 10, 11, and 12 that the results from linear fit indicated y-intercepts with values comparable to the $\Delta y_{\text{increasing}}$ values we had measured. This suggested that even with zero load force F, the sample has a $\Delta y_{\text{increasing}}$ reading, which was not as expected from Equation 6. However, according to Froehle (1999), "it is not enough to measure the relationship between the stretch of the spring and the force (weight) applied to the spring using the relation $F = kx$ because some metal springs have an initial tension that must be overcome before the direct relation is used. The actual relationship for such a spring is $F = kx + b$, where b is the initial tension of the spring." Since Hooke's law is applicable to any system, from this finding we could therefore attribute the y-intercepts as the effect of the initial tension in our samples. The final values of the Young's modulus of samples S2, S3, and S4 were the averages of the E values computed for each respective subsample.

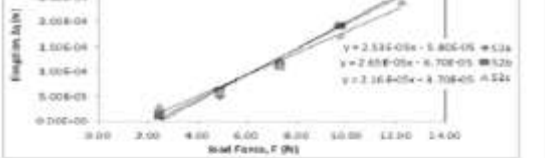

Figure 10. Plot $\Delta y_{\text{increasing}}$ as a function of load force F for the subsamples of concrete with corn husk.

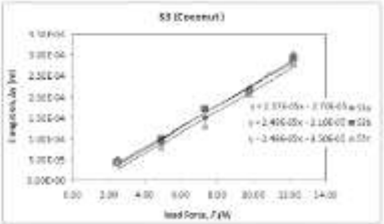

Figure 11. Plot $\Delta y_{\text{increasing}}$ as a function of load force F for the subsamples of concrete with coconut coir.

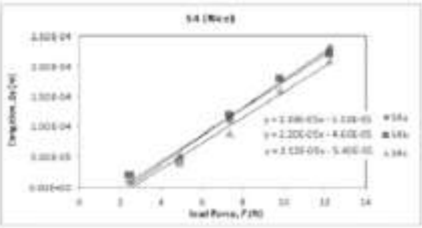

Figure 12. Plot $\Delta y_{\text{increasing}}$ as a function of load force F for the subsamples of concrete with rice hulls.

Summary of the average E values is shown in Table 3. Based on the average values of E in the table, it could be seen that Young's modulus of S4 (concrete with rice hulls) was greatest, followed by S3 (concrete with coconut coir), and S2 (concrete with corn husk).

Table 3. Summary of Young's Modulus Values

Young's modulus from $\Delta y_{\text{increasing}}$								
S2 (concrete with corn husk)			S3 (concrete with coconut coir)			S4 (concrete with rice hulls)		
	E (N/m^2)	± ΔE(x 10^3 N/m^2)		E (N/m^2)	± ΔE(x 10^3 N/m^2)		E (N/m^2)	
S2a	2.7 x 10^3	0.4 x 10^3	S3a	2.9 x 10^3	0.4 x 10^3	S4a	3.1 x 10^3	0.4 x 10^3
S2b	2.9 x 10^3	0.5 x 10^3	S3b	3.1 x 10^3	0.4 x 10^3	S4b	3.6 x 10^3	0.6 x 10^3
S2c	3.3 x 10^3	0.8 x 10^3	S3c	2.9 x 10^3	0.6 x 10^3	S4c	3.8 x 10^3	0.5 x 10^3
ave.	3.0 x 10^3	0.4 x 10^3	ave.	3.0 x 10^3	0.5 x 10^3	ave.	3.5 x 10^3	0.5 x 10^3
Young's modulus from $\Delta y_{\text{decreasing}}$								
S2 (concrete with corn husk)			S3 (concrete with coconut coir)			S4 (concrete with rice hulls)		
	E (N/m^2)	± ΔE(x 10^3 N/m^2)		E (N/m^2)	± ΔE(x 10^3 N/m^2)		E (N/m^2)	± ΔE(x 10^3 N/m^2)
S2a	3.2 x 10^3	0.4 x 10^3	S3a	2.8 x 10^3	0.4 x 10^3	S4a	3.2 x 10^3	0.5 x 10^3
S2b	3.1 x 10^3	0.5 x 10^3	S3b	3.1 x 10^3	0.3 x 10^3	S4b	3.4 x 10^3	0.6 x 10^3
S2c	3.2 x 10^3	0.3 x 10^3	S3c	3.3 x 10^3	0.4 x 10^3	S4c	3.2 x 10^3	0.3 x 10^3
ave.	3.2 x 10^3	0.5 x 10^3	ave.	3.1 x 10^3	0.4 x 10^3	ave.	3.2 x 10^3	0.5 x 10^3

But because the researchers had to consider the range of measured values obtained by taking into account ΔE, a better comparison of the Young's modulus values is shown in Figure 13. Here, the ranges of E values for the three samples just overlapped — it meant that there was no significant difference in the Young's modulus of the samples at all. This indicated that the addition of the admixtures did not contribute a significant effect on the

Young's modulus. Further investigation could be done to reduce errors and validate the measured values of Young's modulus.

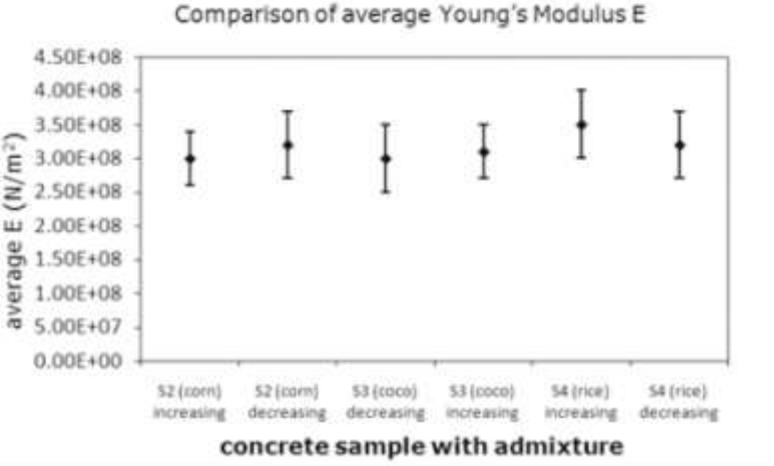

Figure 13. Comparison of the average values of Young's modulus of the different samples.

Conclusions

The addition of admixture to concrete increased the range or scope of the frequency that the concrete could absorb. Thus, concrete added with admixtures were better sound absorbers within the human voice frequency range than concrete with no admixture.

For a specific frequency range of 700–2500 Hz, addition of an admixture shifted the absorption profile of concrete to higher frequencies (from about 1000 Hz to about 1400–1500 Hz). For the 2500–3500 Hz frequency range, addition of an admixture shifted the absorption profile to a lower frequency (from about 3200 Hz to about 3000 Hz).

Concrete added with corn husk powder had the highest sound absorption coefficient, followed by concrete with coconut coir powder, and concrete with rice hull powder.

Based on the average E values of the concrete samples and their corresponding ΔE values, there was no significant effect on the Young's modulus caused by the addition of admixtures.

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