Sound absorption coefficient of coal bottom ash concrete for railway application

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Abstract. A porous concrete able to reduce the sound wave that pass through it. When a sound waves strike a material, a portion of the sound energy was reflected back and another portion of the sound energy was absorbed by the material while the rest was transmitted. The larger portion of the sound wave being absorbed, the lower the noise level able to be lowered. This study is to investigate the sound absorption coefficient of coal bottom ash (CBA) concrete compared to the sound absorption coefficient of normal concrete by carried out the impedance tube test. Hence, this paper presents the result of the impedance tube test of the CBA concrete and normal concrete.

1. Introduction
Railway as one of main transportation mode, faces the demand to guarantee that the value of noise emissions does not exceed the permitted noise limits monitored in tracks for different speed zones which are divided into several categories such as standard, speed and high speed tracks [1-3]. Noise from railway transportation mode can come from two different sources either from construction activities or operational activities. Noise from operational activities is the main source of noise problem produced by railway transportation. It derives from several factors such as audible warning devices of all types, whether mounted on the train or near at grade road crossings, passing by of trains on tangential tracks, train movements on curved track sections which can generate wheel squeal and rail yard operations involving trains stopping and starting, assembling of trains, shunting of cars, retarders, use of Phisignalling devices and repair work [4].

EU (European Union) has funded research aimed at investigating human response to railway noise and vibration and has encouraged the development of engineering mitigation measures for example Cargo vibes, RIVAS (Railway Induced Vibration Abatement Solutions). Individual EU countries have also conducted research to evaluate the effects of the increase in railway noise and vibration. All these studies have concluded that an increase in railway noise or vibration exposure results in an increase in self-reported adverse effects and sleep disturbance [5].

Existing noise level in Malaysia for train operation has been recorded by ERE Consulting Group Sdn Bhd in preparation for the Klang Valley Mass Rapid Transit (KVMRT) project. This detailed environmental impact assessment (DEIA) report was approved by the Department Environment (DOE) on 19th November 2010. Noise barrier has been proposed to mitigate the high noise level due to the train operation [6]. This noise barrier will be built along the track especially at the critical area.
where the train curve will produce high friction between the wheels of the train and the track which resulted in high noise level.

Noise barriers are solid obstruction built between the highway and residential areas. Noise barrier can be built out of wood, concrete, masonry, metal and transparent materials [7]. Noise barrier perform at its best if long enough and high enough to block the view of the road. However, the function of the noise barrier is only as a noise reducer but not completely blocking the sound annoyance [7].

Nowadays, noise barriers are usually made out of concrete, wood or steel. However, there are increasing demands for industries to use waste material as their main material to develop a new product made out of 100% from waste material or incorporation between natural resources and waste material.

In Malaysia, Solid Waste and Public Cleansing Management Act 2007 (Act 672) states that the controlled solid waste was defined as any solid waste that belong to any categories such as household solid waste, construction waste and industrial waste. Among these types of solid wastes, industrial solid waste was considered as the worst type of pollution towards the environment compared to the others. One of the examples of industrial waste is coal bottom ash, product of burning coal in electric generation industry that is located in Tanjung Bin, Jimah and Sultan Salahuddin Abdul Aziz/ Kapar. Coal bottom ash (CBA) is simply disposed-off on open land which poses environmental danger to living beings [8]. The coal bottom ash has different composition of chemical composition depending on different source of coal and mainly composed of silica, alumina and iron with small amounts of calcium, magnesium and sulphate [9]. Large production of coal bottom ash from coal fired power plant has been a major factor to human health problems and environmental pollutions. This is due to the hazardous chemical composition contained in coal bottom ashes that potentially contaminate ground and sources of water near the power plant.

Therefore, due to the lack of research on the new noise barriers from waste material for railway application, this research will emphasize on the new noise barrier material for reducing noise level that currently exist in railway engineering application. The sound absorption coefficient of the CBA material will be measured and tested through impedance tube test and will be compared with the sound absorption coefficient of commonly used concrete for railway noise barrier. This is to improve the ability of noise barrier that is currently used in Malaysia and to reduce noise pollution problem especially for railway application. Besides, the purpose of this study is not limited to reduce the noise pollution in railway application only but may also solve other environmental problems that affect the ecological balance system in Malaysia causes by industrial waste such as coal bottom ash.

2. Material and experimental program

2.1. Material preparation

In order to prepare mix concrete design, the mix concrete samples are prepared based on the calculation that had been analysed. It involves preparation of mold, concrete work and curing. Each processes are being explained in the following subtopics. Table 1 represents the properties of mix concrete design.

| Table 1. Mix design for 0.012 m³ of concrete. |
|-----------------------------------------------|
| Cement (kg)        | Water (kg) | Fine aggregate (kg) | Coarse aggregate (kg) | Bottom ash (kg) |
|---------------------|------------|---------------------|-----------------------|-----------------|
| 6.42                | 2.892      | 6.48                | 13.2                  | 3.394           |

Concrete is made up of three main ingredients which consist of Portland cements, water and aggregates. The ratio of the ingredients changes the properties of final product, which allows the engineer to design concrete that meets their specific needs. Admixtures are added to adjust the concrete mixture for specific performance criteria. Therefore, the selection of material is important in order to determine the require strength of the building and also the lifespan of a building.
However, it is a must to ensure the quality of material that being used in the construction. In this research, there are two type of concrete being casted which is conventional and previous concrete, with different percentage of power plant waste (CBA) as a replacement of fine aggregate in order to determine the best proportion of material that able to absorb sound. Previous concrete can be produce using conventional concrete-making materials, namely cement, all types of coarse and fine aggregates and water.

2.2. Concrete mix design
Table 2 represents the details of concrete mix design proportion that being tested in this research for both samples which involve cube shape and cylinder shape. It can be seen from the table 2 that the percentage of coal bottom ash increase as the fine aggregate decreased. This is because the CBA act as a fine aggregate replacement to compare the acoustic and non-acoustic performance of the CBA concrete mixture with the control concrete which have zero CBA material. The other material such as cement, water and coarse aggregate were kept constant along this concrete preparation.

Table 2. Proportion of concrete mix design for 0.012 m$^3$ of concrete samples for both cube shape and cylinder shape sample.

| Percentage of CBA (%) | Cement (kg) | Water (kg) | Fine aggregate (kg) | Coarse aggregate (kg) | Coal bottom ash (CBA) (gram) |
|----------------------|------------|------------|---------------------|-----------------------|-----------------------------|
| 0 (control)          | 6.42       | 2.892      | 6.48                | 13.2                  | 0                           |
| 10                   | 6.42       | 2.892      | 6.141               | 13.2                  | 339.4                       |
| 20                   | 6.42       | 2.892      | 5.801               | 13.2                  | 678.8                       |
| 30                   | 6.42       | 2.892      | 5.462               | 13.2                  | 1018.2                      |
| 40                   | 6.42       | 2.892      | 5.122               | 13.2                  | 1357.6                      |
| 50                   | 6.42       | 2.892      | 4.783               | 13.2                  | 1697.0                      |
| 75                   | 6.42       | 2.892      | 3.935               | 13.2                  | 2545.5                      |
| 100                  | 6.42       | 2.892      | 3.086               | 13.2                  | 3394.0                      |

Table 3 represents the volume and density of the specimens for impedance tube test purpose. The impedance tube test required two type of test which involve high frequency test and low frequency test. Thus, there are two size of the cylinder shape sample as shown in table 3. The cylinder 1 is for low frequency test and cylinder 2 for high frequency test. Then, the CBA material percentages were being increased from 10% to 100% as shown in table 2.

Table 3. Proportion of concrete mix design for 0.012 m$^3$ of concrete samples for both cube shape and cylinder shape sample.

| Type of specimen | Volume of specimen (m$^3$) | Density materials (kg/m$^3$) |
|------------------|-----------------------------|------------------------------|
| Cylinder 1       | $\pi \times 50\text{mm}^2 \times 100\text{mm}$ | 0.064                        |
| Cylinder 2       | $\pi \times 14.5\text{mm}^2 \times 100\text{mm}$ | 0.064                        |

2.3. Impedance tube test
Impedance tube used in this research as shown in figure 1 is accompanied with AFD 1001 software which has several steps to carry out the test.
Figure 1. Impedance tube used in this research.

To determine the ability of the samples to absorb the noise and to determine the reflecting on the noise that emitted from the train with coal bottom ash concrete, the impedance tube testing had been conducted. The details of dimension of impedance tube that being used to test all the specimens were 29mm in diameter for high frequency while for low frequency will have 100mm in diameter.

The steps to use the impedance tube are divided into 8 steps as follows:
1. The data collected being processed by software named AFD 100. The software being opened and ready to run the data collected.
2. The distance between microphone and the distance between samples being inserted.
3. The calibration process with normal position being conducted at this stage.
4. The microphone being located at the above part of impedance tube.
5. The impedance tube being calibrated and the microphone being switched into opposite direction.
6. The position of the microphones switched between each other.
7. The measurement of low frequency and high frequency are started and the results being recorded.

3. Results and discussions
When a sound wave strikes a material, a portion of the sound energy was reflected back and another portion was absorbed by the material while the rest was transmitted. First, the influence of coal bottom ash percentage as a replacement for fine aggregate in concrete mixtures was tested with low frequency sound wave in impedance tube. The results were presented in table 4.

Figure 2. Sound absorption coefficient of the CBA concrete mixture at low frequency.

Figure 2 represents the value of sound absorption coefficient recorded by the CBA concrete mixture with CBA percentages ranges in between 10% to100%. All the sound absorption coefficients recorded were compared to the reference sample which was control sample where the CBA materials were absent. All the recorded values were summed up into table 4. The highest sound absorption coefficient recorded by all ranges of CBA percentages were at 500 Hz of sound frequency for low frequency of impedance tube test as can be seen in figure 2.
Table 4. The sound absorption coefficient of the coal bottom ash concrete mixture base on its percentages for low frequency.

| CBA % | Control | 10% | 20% | 30% | 40% | 50% | 75% | 100% | Mean |
|-------|---------|-----|-----|-----|-----|-----|-----|------|------|
| 250   | 0.16    | 0.11| 0.13| 0.16| 0.16| 0.06| 0.04| 0.14 | 0.11 |
| 500   | 0.89    | 0.91| 0.88| 0.95| 0.91| 0.90| 0.89| 0.91 | 0.91 |
| 750   | 0.16    | 0.12| 0.17| 0.13| 0.19| 0.22| 0.23| 0.18 | 0.18 |
| 1000  | 0.07    | 0.10| 0.09| 0.08| 0.10| 0.11| 0.10| 0.09 | 0.09 |
| 1250  | 0.11    | 0.09| 0.16| 0.10| 0.15| 0.13| 0.12| 0.09 | 0.12 |
| 1500  | 0.14    | 0.20| 0.21| 0.12| 0.19| 0.25| 0.14| 0.39 | 0.21 |
| 1750  | 0.34    | 0.23| 0.22| 0.37| 0.25| 0.32| 0.35| 0.27 | 0.29 |
| Mean  | 0.27    | 0.25| 0.27| 0.27| 0.28| 0.28| 0.27| 0.29 | -    |

Table 4 presents the recorded values of the sound absorption coefficient by CBA concrete mixture. It can be seen that all the recorded values were above the sound absorption coefficient of the control sample where the CBA materials were absent. This implies that, the CBA concrete mixture had a better acoustic performance compared to the control sample. Thus, the CBA concrete mixture was proven to have a better acoustic performance for low frequency of impedance tube test.

There were 3 samples of coal bottom ash concrete mixtures per batch that were tested with low frequency of noise using impedance tube. Table 4 shows the averages value of sound absorption coefficient for each batch and the value of sound wave being strike to the samples were between 250-1750 Hz. The results revealed that the sound absorption coefficient of the CBA concrete mixture samples with a yellow highlighted that from 10%-100% shows no significance difference compared to the control concrete mixture. The 10% CBA concrete mixtures was the only CBA concrete mixtures that recorded a lower sound absorption coefficient than the control concrete mixture. Hence, the performance of the coal bottom ash concrete mixtures almost same or at the same level to the control sample. It also specifies that the CBA did not deteriorate the acoustic performance of the control sample where the coal bottom ash fine aggregates were absent.

Figure 3 illustrates the recorded values of sound absorption coefficient for the high frequency impedance tube test. The results obtained as presented in figure 3 demonstrate almost a similar pattern with the result obtained for the low frequency impedance tube test. All the sound absorption coefficients recorded were compared with the control sample where the CBA materials were absent. However, the highest recorded of sound absorption coefficient of all ranges of CBA percentages were recorded at 6000 Hz frequency of sound for this high frequency impedance tube test. It can be
disclosed that the highest sound absorption coefficient for both control samples and coal bottom ash concrete mixtures were recorded at 6000 Hz sound wave frequency. Figure 3 also reveals that the maximum sound absorption coefficient was recorded at 40% of coal bottom ash as a fine aggregate replacement of concrete in a range of 1500-6000 Hz of sound wave frequency.

Table 5. The sound absorption coefficient of the coal bottom ash concrete mixture base on its percentages for high frequency.

| CBA % | Control | 10% | 20% | 30% | 40% | 50% | 75% | 100% | Mean |
|-------|---------|-----|-----|-----|-----|-----|-----|------|------|
| 1500  | 0.17    | 0.23| 0.22| 0.22| 0.22| 0.26| 0.26| 0.28 | 0.23 |
| 2000  | 0.18    | 0.26| 0.24| 0.24| 0.24| 0.25| 0.26| 0.26 | 0.24 |
| 2500  | 0.13    | 0.22| 0.22| 0.22| 0.22| 0.23| 0.25| 0.29 | 0.22 |
| 3000  | 0.23    | 0.24| 0.24| 0.21| 0.23| 0.32| 0.40| 0.44 | 0.29 |
| 3500  | 0.35    | 0.30| 0.30| 0.40| 0.43| 0.38| 0.33| 0.34 | 0.35 |
| 4000  | 0.10    | 0.17| 0.17| 0.18| 0.20| 0.21| 0.21| 0.26 | 0.19 |
| 4500  | 0.20    | 0.24| 0.23| 0.26| 0.26| 0.33| 0.35| 0.37 | 0.28 |
| 5000  | 0.16    | 0.38| 0.37| 0.43| 0.44| 0.41| 0.39| 0.40 | 0.37 |
| 5500  | 0.26    | 0.53| 0.55| 0.55| 0.56| 0.58| 0.58| 0.58 | 0.52 |
| 6000  | 0.37    | 0.61| 0.67| 0.73| 0.76| 0.73| 0.71| 0.71 | 0.66 |
| Mean  | 0.21    | 0.32| 0.32| 0.34| 0.36| 0.37| 0.37| 0.39 | -    |

Table 5 reveals all the recorded values of the sound absorption coefficient for high frequency of impedance tube test. It indicates that all the recorded values were above than the control sample where the CBA materials were absent. Thus, it proves that the CBA concrete mixture demonstrates a better acoustic performance for both low and high frequency of impedance tube test compared to the control sample which was known as common concrete which was used as a noise barrier by KTMB.

Table 5 also represents the average value of sound absorption coefficient for each batch and the values of sound wave being strike to the concrete samples were ranged between 1500-6000 Hz to be considered as high frequency impedance tube test. Table 6 exhibit a similar pattern of the result between low and high noise frequency. There was no significant difference of sound absorption coefficient from 10% of CBA concrete mixture to 100% of CBA concrete mixture. However, there was a significant difference in terms of optimal sound frequency being absorbed by the concrete samples as being shown in figure 3.

As presented in table 5 and figure 3, the sound absorption coefficient of all coal bottom ash concrete mixture were higher than the control or normal concrete mixture. Therefore, the development of coal bottom ash concrete mixture in this research was comparable with the normal or control concrete mixture. The acoustic performance of coal bottom ash concrete mixture was better than the acoustic performance of control or normal concrete mixture. The reference concrete presented in both table 4 and 5 recorded the lowest sound absorption coefficient compared to the CBA concrete mixture. The combination of CBA concrete mixture had been found to exhibit better sound absorption behaviour than the control concrete. According to the result obtained in figure 3, 40% of CBA fine aggregate replacement was the best combination for the acoustic concrete mixture giving the most effective sound absorption coefficient.

According to Ramzi Hannan et al.[10], a porous material is effective from the sound absorption point of view when its thickness is approximately one-tenth the wavelength of the incident sound. This could explain why the sound absorption coefficient recorded by all ranges of CBA percentages for both CBA concrete mixture and control samples were highest at certain frequency of sound. The previous research also mentioned that “The maximum absorption occurs at a resonance frequency of a quarter the wavelength of the incident sound” [11]. Thus, the ideal resonance frequency for CBA concrete mixture at all percentages were recorded at 500 Hz and 6000 Hz for low and high frequency of impedance tube test respectively as shown in figure 2 and 3.
The phenomenon where the acoustic performance of the CBA concrete mixture performs better than the control sample without the presence of the CBA materials could be explained by the previous research that stated “The increase in sound absorption coefficient of the coal bottom ash concrete mixture as the percentage of coal bottom ash concrete mixture increase was due to the increase of the porous structure of the concrete due to the vesicular texture, a characteristic of popcorn particles” [12]. A porous concrete creates lots of voids in the concrete and significantly increase the reflection of sound wave in the concrete structure itself and dissipates the sound energy into heat energy due to the porosity effects [13]. Thus, this explanation could prove why the CBA concrete mixture performs better than control sample where the CBA materials were absent in terms of acoustic performance.

Table 6. Sound absorption coefficient provided by akustik.ua.

| Material                              | Frequency (Hz) |
|---------------------------------------|----------------|
|                                       | 125            |
|                                       | 250            |
|                                       | 500            |
|                                       | 1000           |
|                                       | 2000           |
|                                       | 4000           |
| Masonry wall                          |                |
| Rough concrete                        | 0.02           |
| Smooth unpainted concrete             | 0.01           |
| Smooth concrete, painted or glazed    | 0.01           |
| Breeze block                          | 0.2            |
| Plaster on solid wall                 | 0.04           |
| Plaster, lime or gypsum on solid backing | 0.03          |

Table 6 represents the details of the sound absorption coefficient of the commonly used noise barrier materials and the highlighted yellow colour were the commonly used material as a noise barrier in KTMB industry which were rough concrete, smooth unpainted concrete and plaster on solid wall. These types of materials were the materials that were found at the four railway stations involved in this research. All the materials recorded a lower sound absorption coefficient compared with the CBA concrete mixture at the same frequency of sound.

Table 7. Sound absorption coefficient comparison between CBA concrete mixture with non-CBA concrete mixture.

| Material                              | Frequency (Hz) |
|---------------------------------------|----------------|
|                                       | 125            |
|                                       | 250            |
|                                       | 500            |
|                                       | 1000           |
|                                       | 2000           |
|                                       | 4000           |
| Masonry wall                          |                |
| Rough concrete                        | 0.02           |
| Smooth unpainted concrete             | 0.01           |
| Plaster on solid wall                 | 0.04           |
| CBA concrete mixture                  | 0.11           |

Table 7 indicates the comparison values of the sound absorption coefficient recorded by both CBA concrete mixture and non-CBA concrete mixture concrete that was commonly used as a noise barrier in KTMB industry. From table 8, it can be distinguished that the CBA concrete mixture perform significantly better acoustic performance by recorded significantly higher sound absorption coefficient than the commonly used concrete mixture without the presence of CBA materials.

4. Conclusion
The results obtained in this research proved that the CBA concrete mixture performed much better in terms of both acoustic and non-acoustic performance. Thus, the main objectives of this study was proven since the acoustic and non-acoustic performance of the CBA concrete mixture was evaluated and compared to the existing normal concrete mixture.
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