ACOUSTIC AND NON-ACOUSTIC PERFORMANCE OF COAL BOTTOM ASH AS SOUND ABSORPTIVE MATERIAL FOR REDUCING RAILWAY NOISE LEVEL

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DEDICATION

I dedicate this dissertation to my loving parent
Abah and Mama
My sweet husband Ahmad Fattah Al Islam
My sons
My supportive supervisor Ts. Dr. Shahiron Shahidan
Who has offered unwavering support, love, encouragement
and prays of day and night during the past four years of my doctoral journey.

Thanks Mama Abah
for always believing in me and for encouraging me to strive my dreams

Thanks my dear lovely husband
caused always cheered me on when I was discouraged,
wiped my tears away when the great research catasrophes stuck and he has most
importantly been 100% confident in my ability this get this done.

Along with all hard working and respected lectures and friends.

Thank you very much and love you all.
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ABSTRACT

The development of new technology and rapid development in many countries have led to various types of pollution, especially acoustic pollution in urban areas. Furthermore, the huge production of Coal Bottom Ash (CBA) is treated as waste and often placed into impoundment ponds, silos or landfills, which has contributed to environmental issues. Usage of CBA in concrete production in reducing railway noise pollution reduce the environmental pollution. This study presents the acoustic and non-acoustic performance for a new concrete product that consists mainly of CBA. Grade 30 MPa concrete was cast with varying replacement percentages (0% to 100%) of CBA as fine aggregate replacement in concrete mixture. The specimens were cured for periods of 7, 28 and 90 days. The non-acoustic performance of CBA concrete demonstrated similar or even better performance than normal concrete by conducting compressive strength, splitting tensile strength, water absorption, water permeability and ultrasonic pulse velocity. The increase in CBA percentage in the concrete mixture has affected the compressive strength and splitting tensile strength of the sample which were lower than that of control concrete. CBA concrete can be recommended as good concrete due to its absorption properties. Based on the sound test conducted according to ISO 11654: 1997, it was found that CBA concrete can be classified as Class D (absorption). Class D materials are able to absorb more than 30% of sound by conducting impedance tube and reverberation time. In addition, the Noise Reduction Coefficient (NRC) performance for CBA concrete addresses more than 35% of the absorbed railway sound. CBA concrete showed an improvement in acoustic properties compared to normal concrete as it is able to reduce up to 3.74 dB of the existing railway noise level while normal concrete can only reduce up to 1.94 dB of the existing noise level.
ABSTRAK

Pembangunan negara yang semakin maju dan canggih dengan teknologi baru telah mendatangkan pelbagai jenis pencemaran antaranya pencemaran bunyi hingar terutamanya di sekitar kawasan bandar. Selain itu, pengeluaran sisa arang batu iaitu abu arang bawah (CBA) yang semakin membimbangkan yang telah dihasilkan dianggap sebagai sisa dan sering dibuang di dalam kolam timbunan, silo atau tapak pelupusan yang telah menyumbang kepada isu-isu alam sekitar. Penggunaan CBA dalam penghasilan konkrit bagi mengurang pencemaran bunyi kereta api mampu mengurangkan pencemaran alam sekitar. Kajian ini dilakukan untuk mengkaji prestasi akustik dan bukan akustik bagi konkrit yang dihasilkan daripada campuran sisa arang batu. Campuran konkrit bergradi 30 MPa dihasilkan dengan pelbagai variasi peratusan penggantian (0% sehingga 100%) dari CBA sebagai pengganti kepada agregat halus (pasir) di dalam campuran konkrit. Spesimen tersebut telah diawet selama 7, 28 dan 90 hari. Berdasarkan ujian yang telah dilakukan ianya mendapati bahawa prestasi konkrit campuran adalah sama atau lebih baik daripada konkrit biasa dengan melakukan ujian kekuatan mampatan, kekuatan tegangan, peyerapan air, kebolehtelapan air dan halaju nadi ultrasonik. Peningkatan jumlah peratusan CBA dalam campuran konkrit telah mempengaruhi kekuatan mampatan dan kekuatan tegangan yang lebih rendah daripada konkrit biasa. Selain itu, kadar serapan air dan penyusupan air bagi konkrit campuran CBA adalah lebih tinggi daripada konkrit biasa. Kadar serapan air bagi konkrit CBA meningkat apabila peratusan penggunaan CBA di dalam konkrit meningkat. Hasil ujian bunyi yang dilakukan terhadap konkrit campuran CBA mendapati nilai serapan bunyi adalah di kelas D (ISO 11654:1997). Selain itu juga, prestasi pekali pengurangan bunyi (NRC) bagi konkrit campuran CBA menunjukan lebih daripada 35% bunyi diserap. Ianya juga telah menunjukan potensi yang baik dari konkrit biasa iaitu kemampuannya untuk mengurangkan kadar bunyi keretapi sebanyak 3.74 dB berbanding konkrit biasa 1.94 dB.
CONTENTS

DECLARATION OF THESIS STATUS  iii
EXAMINERS’DECLARATION  iv
TITLE  v
STUDENT’S DECLARATION  vi
DEDICATION  vii
ACKNOWLEDGMENT  viii
ABSTRACT  ix
ABSTRAK  x
CONTENTS  xi
LIST OF TABLE  xiii
LIST OF FIGURE  xiv
LIST OF SYMBOLS AND ABBREVIATIONS  xvii
LIST OF APPENDICES  xix

CHAPTER 1  INTRODUCTION  1
  1.1 Background of the study  1
  1.2 Problem statement  4
  1.3 Objective of the study  6
  1.4 Scope of the study  7
  1.5 Significant of the study  8
  1.6 Thesis outline  9

CHAPTER 2  LITERATURE REVIEW  10
  2.1 Introduction  10
  2.2 Waste material  11
     2.2.1 The use of commercial waste in concrete production  12
     2.2.2 Industrial waste  16
2.3 Coal bottom ash 18
   2.3.1 Disposal and usage of coal bottom ash 19
   2.3.2 Coal bottom ash in concrete production 21
2.4 Physical properties of coal bottom ash 25
   2.4.1 Particle size 25
   2.4.2 Fineness modulus 25
   2.4.3 Specific gravity 26
   2.4.4 Chemical composition 27
2.5 Properties of fresh coal bottom ash concrete 28
2.6 Properties of hardened coal bottom ash concrete 29
   2.6.1 Density 29
   2.6.2 Compressive strength 30
   2.6.3 Splitting tensile strength 31
   2.6.4 Water absorption 32
2.7 Previous study on the usage of coal bottom ash 33
2.8 Noise pollution 37
   2.8.1 Railway noise and related factor 39
   2.8.2 Railway system issues in Malaysia 43
2.9 Noise reduction device 45
   2.9.1 Noise barriers as sound absorber 46
2.10 Summary 51

CHAPTER 3 METHODOLOGY 53
3.1 Introduction 53
3.2 Research flow 55
3.3 Noise monitoring 55
   3.3.1 Selection of study area 55
   3.3.2 Data collection and equipment selection 57
3.4 Preparation of raw materials for concrete specimens 60
   3.4.1 Water 61
   3.4.2 Portland cement 61
   3.4.3 Aggregates 61
   3.4.4 Coal Bottom Ash 62
<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.5 Material characterisation testing</td>
<td>65</td>
</tr>
<tr>
<td>3.5.1 Sieve analysis</td>
<td>65</td>
</tr>
<tr>
<td>3.5.2 Specific gravity</td>
<td>66</td>
</tr>
<tr>
<td>3.5.3 Bulk density</td>
<td>68</td>
</tr>
<tr>
<td>3.5.4 Chemical and microstructural characterisation</td>
<td>68</td>
</tr>
<tr>
<td>3.6 Design calculation for CBA concrete</td>
<td>70</td>
</tr>
<tr>
<td>3.7 Preparations of concrete specimen</td>
<td>71</td>
</tr>
<tr>
<td>3.8 Non acoustic performance testing</td>
<td>73</td>
</tr>
<tr>
<td>3.8.1 Workability</td>
<td>74</td>
</tr>
<tr>
<td>3.8.2 Density of hardened concrete</td>
<td>75</td>
</tr>
<tr>
<td>3.8.3 Compressive strength</td>
<td>75</td>
</tr>
<tr>
<td>3.8.4 Splitting tensile strength</td>
<td>76</td>
</tr>
<tr>
<td>3.8.5 Water absorption</td>
<td>77</td>
</tr>
<tr>
<td>3.8.6 Water permeability</td>
<td>78</td>
</tr>
<tr>
<td>3.8.7 Ultrasonic pulse velocity</td>
<td>80</td>
</tr>
<tr>
<td>3.9 Acoustic performance testing</td>
<td>81</td>
</tr>
<tr>
<td>3.9.1 Impedance tube</td>
<td>81</td>
</tr>
<tr>
<td>3.9.2 Reverberation time</td>
<td>84</td>
</tr>
<tr>
<td>3.9.3 Sound absorption coefficient (SAC) and Noise reduction coefficients (NRC)</td>
<td>88</td>
</tr>
<tr>
<td>3.10 Summary</td>
<td>89</td>
</tr>
</tbody>
</table>

CHAPTER 4 NOISE LEVEL IDENTIFICATION 90

4.1 Introduction                                                     90

4.2 Determination of noise level                                     90

4.2.1 Different locations                                            90

4.2.2 Day versus Night                                               98

4.2.3 Different types of trains                                       100

4.3 Summary                                                          102
CHAPTER 5 PROPERTIES OF CONCRETE INCORPORATING CBA AS FINE AGGREGATE REPLACEMENT

5.1 Introduction 103
5.2 Characteristic of aggregate and CBA 104
   5.2.1 Sieve analysis 104
   5.2.2 Specific gravity 108
   5.2.3 Bulk density 112
   5.2.4 Chemical composition 113
   5.2.5 Summary characterisation of materials 116
5.3 Properties of fresh concrete 117
5.4 Hardened concrete properties 120
   5.4.1 Dry density 120
   5.4.2 Compressive strength 123
   5.4.3 Splitting tensile strength 126
   5.4.4 Water absorption 130
   5.4.5 Water permeability 133
   5.4.6 Ultrasonic pulse velocity 138
5.5 Summary 141

CHAPTER 6 ACOUSTIC PROPERTIES OF CBA CONCRETE 144
6.1 Introduction 144
6.2 Impedance tube test 144
6.3 Reverberation room test 153
6.4 Prediction or reduction railway noise (Decibel drop) 160
6.5 Summary 163

CHAPTER 7 CONCLUSION AND RECOMMENDATION FOR FUTURE WORK 164
7.1 Introduction 164
7.2 Conclusion 164
   7.2.1 Determination railway noise level 164
   7.2.2 Non-acoustic performance of coal bottom ash concrete 165
   7.2.3 Acoustic performance of coal bottom ash concrete 167
LIST OF TABLE

2.1 Previous research studies on the type of waste material in concrete production 12
2.2 Previous research studies on the usage of coal bottom ash in construction industry 21
2.3 Previous research studies on the usage of coal bottom ash in concrete production 22
2.4 Fineness modulus of coal bottom ash based on previous study 26
2.5 Specific gravity of coal bottom ash based on previous study 27
2.6 Chemical composition of coal bottom ash at different power plant station 27
2.7 Workability of coal bottom ash concrete 28
2.8 Density of coal bottom ash concrete 29
2.9 Compressive strength of coal bottom ash concrete at 28 days of curing age 30
2.10 Splitting tensile strength of coal bottom ash concrete 32
2.11 Water absorption of coal bottom ash concrete 33
2.12 Previous research on the utilization of coal bottom ash fine aggregate in concrete production 34
2.13 Comparative sound level 37
2.14 Previous study on the transportation noise 38
2.15 Types of railway noise 40
2.16 Issue related to the railway system in Malaysia based on previous research 44
2.17 Limiting sound level for railways in Malaysia 45
<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.18</td>
<td>Active and Passive ways for reducing noise</td>
<td>46</td>
</tr>
<tr>
<td>2.19</td>
<td>Previous study on the types of material used as sound absorptive material</td>
<td>50</td>
</tr>
<tr>
<td>3.1</td>
<td>Mix design per m$^3$ of normal concrete</td>
<td>70</td>
</tr>
<tr>
<td>3.2</td>
<td>Concrete mix design for each percentage of CBA as fine aggregate replacement for 1m$^3$ of concrete</td>
<td>71</td>
</tr>
<tr>
<td>3.3</td>
<td>Specimen sizes used in this research</td>
<td>72</td>
</tr>
<tr>
<td>3.4</td>
<td>Number of sample for each test</td>
<td>72</td>
</tr>
<tr>
<td>4.1</td>
<td>Limiting sound level for railways in Malaysia</td>
<td>91</td>
</tr>
<tr>
<td>4.2</td>
<td>Maximum and minimum noise level recorded at different railway stations</td>
<td>96</td>
</tr>
<tr>
<td>4.3</td>
<td>Maximum and minimum noise level recorded at different railway station (day and night)</td>
<td>99</td>
</tr>
<tr>
<td>4.4</td>
<td>Percentage difference of noise level produced by different type trains.</td>
<td>100</td>
</tr>
<tr>
<td>5.1</td>
<td>Sieve analysis of fine aggregate</td>
<td>104</td>
</tr>
<tr>
<td>5.2</td>
<td>Sieve analysis of CBA</td>
<td>105</td>
</tr>
<tr>
<td>5.3</td>
<td>Fineness modulus of CBA reported by previous researchers</td>
<td>107</td>
</tr>
<tr>
<td>5.4</td>
<td>Percentage difference for Fineness Modulus of CBA between obtained from the present study and those reported in standard and previous researchers</td>
<td>107</td>
</tr>
<tr>
<td>5.5</td>
<td>Comparison between specific gravity values of CBA obtained from the present study and the one reported in previous researcher</td>
<td>109</td>
</tr>
<tr>
<td>5.6</td>
<td>Percentage difference specific gravity values of CBA obtained from the present study and those reported by previous researchers</td>
<td>110</td>
</tr>
<tr>
<td>5.7</td>
<td>Density of CBA and fine aggregate obtained from the present study and those reported by previous researches</td>
<td>112</td>
</tr>
<tr>
<td>5.8</td>
<td>Chemical composition of fine aggregate and CBA obtained from different power plant stations</td>
<td>114</td>
</tr>
<tr>
<td>Section</td>
<td>Title</td>
<td>Page</td>
</tr>
<tr>
<td>---------</td>
<td>-------------------------------------------------------------------------------------------</td>
<td>------</td>
</tr>
<tr>
<td>5.9</td>
<td>Physical properties of sand and coal bottom ash</td>
<td>116</td>
</tr>
<tr>
<td>5.10</td>
<td>Hardened density of coal bottom ash concrete at 7, 28 and 90 days</td>
<td>121</td>
</tr>
<tr>
<td>5.11</td>
<td>Compressive strength of CBAC at 7, 28 and 90 days</td>
<td>123</td>
</tr>
<tr>
<td>5.12</td>
<td>Splitting tensile strength of CBAC at 7, 28 and 90 days</td>
<td>126</td>
</tr>
<tr>
<td>5.13</td>
<td>Percentage difference of splitting tensile strength with compressive strength of coal bottom ash concrete</td>
<td>129</td>
</tr>
<tr>
<td>5.14</td>
<td>Water absorption of CBAC</td>
<td>130</td>
</tr>
<tr>
<td>5.15</td>
<td>Water permeability of CBAC</td>
<td>134</td>
</tr>
<tr>
<td>5.16</td>
<td>Ultrasonic pulse velocity of CBAC as replacement of fine aggregate in concrete</td>
<td>138</td>
</tr>
<tr>
<td>5.17</td>
<td>Concrete quality grading as per BS 1881:1983</td>
<td>140</td>
</tr>
<tr>
<td>6.1</td>
<td>Sound absorption coefficient for CBA concrete at low frequency range</td>
<td>145</td>
</tr>
<tr>
<td>6.2</td>
<td>Sound absorption coefficient for CBA concrete at high frequency range</td>
<td>146</td>
</tr>
<tr>
<td>6.3</td>
<td>NRC performance of CBA concrete</td>
<td>149</td>
</tr>
<tr>
<td>6.4</td>
<td>Density, strength and NRC value for CBA concrete</td>
<td>150</td>
</tr>
<tr>
<td>6.5</td>
<td>Sound absorption coefficient comparison between CBA concrete mixtures with non-CBA concrete mixture</td>
<td>153</td>
</tr>
<tr>
<td>6.6</td>
<td>Sound absorption coefficient for CBAC acoustic panels</td>
<td>158</td>
</tr>
<tr>
<td>6.7</td>
<td>Rating of sound absorption for CBAC acoustic panels according to ISO 11654 :1997</td>
<td>160</td>
</tr>
<tr>
<td>6.8</td>
<td>Decibel drop of railway noise level at each station</td>
<td>162</td>
</tr>
</tbody>
</table>
# LIST OF FIGURE

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1</td>
<td>Location of coal-fired power plants in Malaysia</td>
</tr>
<tr>
<td>2.1</td>
<td>Production of coal ash at coal fired thermal power plant</td>
</tr>
<tr>
<td>2.2</td>
<td>Tanjung Bin Power Plant Station</td>
</tr>
<tr>
<td>2.3</td>
<td>Ash pond</td>
</tr>
<tr>
<td>2.4</td>
<td>Railways noise type</td>
</tr>
<tr>
<td>2.5</td>
<td>Level of railway noise and their associated speed dependency</td>
</tr>
<tr>
<td>2.6</td>
<td>Alteration of noise paths using a noise barriers</td>
</tr>
<tr>
<td>2.7</td>
<td>Reflection, absorption and transmission of sound</td>
</tr>
<tr>
<td>2.8</td>
<td>Viscous drag mechanism of absorption in porous material</td>
</tr>
<tr>
<td>3.1</td>
<td>Research flow chart</td>
</tr>
<tr>
<td>3.2</td>
<td>KTM route map in Malaysia</td>
</tr>
<tr>
<td>3.3</td>
<td>(a) Locomotive intercity diesel train, (b) Electric Train Service (ETS) that operated in the study area,</td>
</tr>
<tr>
<td>3.4</td>
<td>Sound Level Meter (SLM) device used in the research</td>
</tr>
<tr>
<td>3.5</td>
<td>SLM positioned near Electric Train Services (ETS) at Gemas Station.</td>
</tr>
<tr>
<td>3.6</td>
<td>(a) SLM positioned near a locomotive train diesel engine, (b) SLM positioned near the pantograph of the ETS</td>
</tr>
<tr>
<td>3.7</td>
<td>Coal Bottom Ash (CBA)</td>
</tr>
<tr>
<td>3.8</td>
<td>Location of Tanjung Bin Power Plant Station</td>
</tr>
<tr>
<td>3.9</td>
<td>Material preparation for CBA before it is used in concrete mixture</td>
</tr>
<tr>
<td>3.10</td>
<td>Mechanical shaker</td>
</tr>
<tr>
<td>3.11</td>
<td>Process involved in the specific gravity test</td>
</tr>
<tr>
<td>3.12</td>
<td>SEM and XRF Machine</td>
</tr>
</tbody>
</table>
3.13 The curing process of concrete specimens 73
3.14 Slump testing 74
3.15 Compressive strength testing. 76
3.16 Tensile splitting strength test setup 77
3.17 Processes involved in the water absorption test 78
3.18 Water permeability testing 80
3.19 100 mm concrete sample for impedance tube testing 82
3.20 (a) Impedance tube machine 83
     (b) Calibration process of microphone
     (c) Impedance tube test in progress
3.21 Specimens arrangement in the mini chamber 85
3.22 All the perimeter surface area of specimen were sealed with reflective material 85
3.23 Schematic drawing and microphone positions. 86
3.24 (a) CBA concrete sample inside the mini chamber 87
     (b) signal analyzer
4.1 (a) Noise level recorded at Kluang station 92
     (b) Noise level recorded at Segamat station 93
4.2 (a) Noise level recorded at Gemas station 94
     (a) Noise level recorded at Kuala Lumpur station 95
4.3 Kuala Lumpur Railway station with enclosure structure 97
4.4 Location of study area; (a) Kluang railway station, (b) Segamat railway station and (c) Gemas railway station 98
4.5 Type of train operates in the selected area of study; (a) Locomotive Diesel Train/ Freight Train, (b) KTM commuter and (c) ETS. 101
5.1 Sieve analysis for sand and CBA 106
5.2 Specific gravity testing; (a) sand and (b) CBA 109
5.3 Vesicular texture of coal bottom ash 111
5.4 Relationship between slump and concrete containing different percentage of CBA 117
5.5 Density of CBA concrete at different percentage 122
<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.6</td>
<td>Compressive strength versus curing days</td>
</tr>
<tr>
<td>5.7</td>
<td>Splitting tensile strength versus percentage replacement at all curing age.</td>
</tr>
<tr>
<td>5.8</td>
<td>Water absorption CBA concrete versus percentage of CBA</td>
</tr>
<tr>
<td>5.9</td>
<td>Relationship between water absorption and compressive strength of CBA concrete at 28 days of curing age</td>
</tr>
<tr>
<td>5.10</td>
<td>Water permeability with curing age of CBA concrete</td>
</tr>
<tr>
<td>5.11</td>
<td>Particle image at 500x magnification of (a) fine aggregate and (b) CBA</td>
</tr>
<tr>
<td>5.12</td>
<td>Relationship between permeability coefficients and water absorption of CBA concrete.</td>
</tr>
<tr>
<td>5.13</td>
<td>Variation of pulse velocity with curing age</td>
</tr>
<tr>
<td>6.1</td>
<td>Comparison of sound absorption coefficient with different percentage of CBA (low and high frequency)</td>
</tr>
<tr>
<td>6.2</td>
<td>Relationship between NRC value and hardened density of CBA concrete.</td>
</tr>
<tr>
<td>6.3</td>
<td>Relationship between NRC value and compressive strength of CBA concrete.</td>
</tr>
<tr>
<td>6.4</td>
<td>RT mini chamber</td>
</tr>
<tr>
<td>6.5</td>
<td>Reverberation time for an empty chamber and chamber occupied with CBAC acoustic panels</td>
</tr>
<tr>
<td>6.6</td>
<td>Sound absorption performance of CBAC acoustic panels in the reverberation chamber</td>
</tr>
<tr>
<td>6.7</td>
<td>Rating curves for CBAC acoustic panels</td>
</tr>
</tbody>
</table>
LIST OF SYMBOLS AND ABBREVIATIONS

dB - Decibel
dBA - A weighted decibels
Am - Ante meridiem (Before noon)
Pm - Post meridiem (After noon)
kPa - Kilo pascal
Pa - Pascal
α - Sound absorption coefficient
$\alpha_{pi}$ - Arithmetic mean value of sound absorption coefficient
$\alpha_{w}$ - Weighted absorption coefficient
$\alpha_{s}$ - Sabine’s absorption coefficient
m - Meter
mm - Millimeter
kg - Kilogram
S - Second
W - Watt
MW - MegaWatt
GW - GigaWatt
% - Percent
Hz - Hertz
ACAA - American Coal Ash Association
ASTM - American Society for Testing and Materials
BS - British Standard
CBA - Coal Bottom Ash
CBAC - Coal Bottom Ash Concrete
CO$_2$ - Carbon dioxide
DOE - Department of Environment
EHS - Environmentally Hazardous Substance
EN - European Norm
EQA - Environment Quality Act
<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>ERL</td>
<td>Expres Rail Line</td>
</tr>
<tr>
<td>ETS</td>
<td>Electric Train Service</td>
</tr>
<tr>
<td>FBA</td>
<td>Fine Bottom Ash</td>
</tr>
<tr>
<td>FGD</td>
<td>Fuel Gas Desulphurization</td>
</tr>
<tr>
<td>IPP</td>
<td>Independent Power Producers</td>
</tr>
<tr>
<td>ISO</td>
<td>International Standards Organization</td>
</tr>
<tr>
<td>KTMB</td>
<td>Keretapi Tanah Melayu Berhad</td>
</tr>
<tr>
<td>MPa</td>
<td>Mega Pascal</td>
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<tr>
<td>MRT</td>
<td>Mass Rapid Transit</td>
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<tr>
<td>MSW</td>
<td>Municipal Solid Waste</td>
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<tr>
<td>NRC</td>
<td>Noise Reduction Coefficient</td>
</tr>
<tr>
<td>NRDs</td>
<td>Noise Reduction Device</td>
</tr>
<tr>
<td>PCC</td>
<td>Portland Cement Concrete</td>
</tr>
<tr>
<td>RHA</td>
<td>Rice Husk Ash</td>
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<tr>
<td>RT</td>
<td>Reverberation Time</td>
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<tr>
<td>SAC</td>
<td>Sound Absorption Coefficient</td>
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<tr>
<td>SCC</td>
<td>Sel- compacting concrete</td>
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<tr>
<td>SEM</td>
<td>Scanning Electron Microscopy</td>
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<tr>
<td>SF</td>
<td>Silica Fume</td>
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<tr>
<td>SLM</td>
<td>Sound Level Meter</td>
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<tr>
<td>SPAD</td>
<td>Suruhanjaya Pengangkutan Awam Darat</td>
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<tr>
<td>SW</td>
<td>Schedule Waste</td>
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<tr>
<td>TNB</td>
<td>Tenaga Nasional Berhad</td>
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<tr>
<td>UPV</td>
<td>Ultrasonic Pulse Velocity</td>
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<tr>
<td>WBA</td>
<td>Washed Bottom Ash</td>
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<tr>
<td>XRF</td>
<td>X-Ray Fluorescent</td>
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</tbody>
</table>
CHAPTER 1

INTRODUCTION

1.1 Background of the study

Noise is one of the most negative impacts of transport affecting the quality of the environment. It affects a large number of people as it often causes annoyance and irritation which affect various human activities. Noise pollution from the transportation sector can interfere with the environment. Even though railways are one of the most environmentally friendly types of transportation due to its energy efficiency and emittance of less hazardous substances, railway noise produced by freight trains, speed trains and high-speed trains remains a major environmental issue. The investigation of railway noise is getting more attention among researchers as it is continuously reviewed from year to year starting from 2010 to 2019.

In Malaysia, a handful of studies are limited to surveys of railway noise status and its influence on the community. However, various techniques can be employed to reduce railway noise at source including dampers, sleepers, barriers, tunnels and so on. A noise barrier wall is one of the most economic and innovative methods for reducing noise. Many industries have come out with many types of noise barriers which can be built out of wood, concrete, masonry, metal and transparent materials. It also comes in various shapes such as hollow blocks or panels. However, based on previous research, noise barriers made of recycled aggregate, recycled rubber, recycled ceramic industry waste and other types of waste have also been invented.
Waste has long been a major issue for the environment, the society and the economy (Arenas et al., 2015). Industrial waste poses a potential serious hazard to the environment as most industrial processes employ chemicals or chemically produced materials (Aja et al., 2016). In Malaysia, the manufacturing sector was first identified as generators of toxic and hazardous waste which is an environmental hazard for living things. Due to rapid development, the quantity of solid waste generated every year continues to increase. The quantity of solid waste in Malaysia is projected to increase from 19,100 tonnes per day in 2005 to 30,000 tonnes per day by 2020 with the annual population growth rate 2.5 per cent (Ali et al., 2018)

One of the manufacturing activities that contribute to the generation of industrial waste is electricity power generation. Due to the increasing demand for electricity every year, several coal fired thermal power plants have been set up in large numbers in the country to meet consumer demand (Singh & Siddique, 2013).

There are several coal power plants located in Malaysia namely Tanjung Bin, Jimah, Sultan Salahuddin Abdul Aziz/Kapar and Sultan Azlan Shah/Manjung coal power plant stations as shown in Figure 1.1. Most of these power plants have been using coal as the main source for generating electricity. This, in turn, produces large volumes of coal ash (Oh et al., 2010). Fly ash, coal bottom ash (CBA), boiler slag and Flue Gas Desulphurisation (FGD) sludge are wastes produced during the combustion process in coal-fired power plants. According to Kockwood & Evans (2012), coal ash is a hazardous waste where the toxic remains of coal burning in power plants are full of chemicals that cause cancer, developmental disorders and reproductive problems. Coal bottom ash (CBA) is still being treated as solid waste material which is disposed of on open land and is not used in any form (Singh & Siddique, 2015).

The massive quantity of CBA produced from the coal combustion process for electricity generation poses a risk to human health and the environment. CBA can contaminate ground or surface water and subsequently poison living organisms. Therefore, CBA is gradually being incorporated in the construction industry as road base layers, pavements, structural fill, drainage media, aggregate for concrete and also in manufactured soil products to reduce environmental pollution (Kuo, Poon & Etxeberria, 2013). In previous research, CBA has been used as a partial replacement
of natural aggregates (fine aggregate or coarse aggregate). It possesses high fire resistance due to its wide evaporation plateau (Abubakar et al., 2012a).

![Figure 1.1: Location of coal-fired power plants in Malaysia (Edited from Muhardi et al., 2010)](image)

This research mainly studies the potential application of CBA in concrete which can hopefully be used as absorptive material in railway noise barriers. The usage of CBA as an absorbent material in concrete mixture has demonstrated similar properties to other conventional materials used for sound absorbing applications (Arenas et al., 2013). Besides that, the findings of this study may also help reduce noise pollution which poses a risk to both humans and the environment.
1.2 Problem Statement

Coal is the main source used for the generation of electricity worldwide. According to Muhardi et al., (2010), it has been recognised as an important source of fuel in Malaysia. The demand for coal for electricity generation increased sharply from an estimated 6.03 million tonnes in 2000 to between 19 to 20 million tonnes per annum by 2010 (Mohamed & Teong, 2010). It is also expected to increase by more than 30 million tonnes per annum by 2020. Coal remains one of the main sources for energy generation due to its low price and it being the most abundantly available fossil fuel in Malaysia (Suruhanjaya Tenaga, 2018).

CBA is one of the non-combustible materials that is produced after the coal combustion process for electricity generation. CBA is the coarser part which is collected at the bottom of the coal furnace. It consists of angular ash particles which are too heavy and large to be carried up into smoke stacks. Typically, CBA is simply disposed of on open land after the burning process. Due to coal combustion, an increased volume of CBA is continually being disposed of on land. The volume of CBA that is being disposed of is increasing by the year. According to the Department of Environment (DOE) Malaysia, 364,425.95 MT/year of coal ash was generated in 2010 while the total quantity of coal ash generated is 342,560.39 MT/year in 2011. This represents an increase of 6% in coal ash production in 2011. Meanwhile, in Tanjung Bin power plant has produced 50,000 metric tonnes of coal ash (fly and bottom ash) every month (Abdullah et al., 2018).

Due to the huge amount disposal of CBA has contributed to environmental pollution such as the pollution of Emory and Clinch Rivers in Kingston, Tennessee. This also happened to Tanjung Bin power plant which is required large area for disposal storage of CBA (Abdullah et al., 2018). The disposal of CBA have its disadvantages in the sense when the pond site is not lined with concrete has cause the heavy metals tends to leach into natural ground water and contamination to the environmental (Abubakar et al., 2012). According to Gottlieb et al., (2010), the water in the rivers contained heavy metals such as arsenic and elevated levels of other toxic metals such as lead, thallium, barium, cadmium, chromium, mercury and nickel. In
LIST OF APPENDIX

A  Supportive document/Letter
B  Concrete mix design
C  Experimental data
D  List of publication
Malaysia, CBA is classified as Scheduled Waste SW 104 (Environmental Quality Act) and hazardous waste due to its toxicity.

On the other side, increase in human population and daily activities has caused traffic congestion, which is nowadays the biggest issue faced by road users. However, the Malaysian government has begun to gradually overcome the issues by providing more railways service in Malaysia. The railway services provided by the government help ease the public’s movement in both urban and rural areas (Khalid et al., 2014).

The demand for usage of trains among the public faces several challenging issues such as noise and vibration issues in residential areas as reported in Sinar Harian on 28 April 2016. According to the article, residents of Sri Teratai Apartment in Puchong Jaya claimed that noise from railway services has affected their daily activities. They had difficulty sleeping. Babies and the elderly were especially disturbed by the noise generated by trains. This also be supported by Fawwaz et al., (2013) where found the residents that lived nearby LRT station Taman Melati also faced the same problem which is difficulties to sleep early due to the noise from LRT line which is close to their neighbourhood.

According to Shahidan et al., (2017) most of measured noise levels of railways reached more than 90 dB which exceeds the permissible noise limit set by the Department of Environment (DOE) Malaysia. The noise limits for day and night are 60 dB and 50 dB respectively for noise sensitive areas or low density residential areas.

Considering the increase in noise emissions from railway services in residential areas, environmentally friendly materials is needed. For example, coconut shell powder and rubber ash as well as other waste products have been used in the construction industry especially in concrete production. Therefore, based on the issue highlighted, this study has selected CBA as absorptive material in reducing noise pollution. CBA is considered as a waste product which pollutes the environment.

CBA have been used in concrete production as cement replacement and fine aggregate replacement previous researchers. It has the potential to be used in concrete mixes. Most of researches used CBA to improve the mechanical properties of concrete such strength development and durability of the concrete since the findings shows the similar pattern with the normal concrete. Eventhough, there were research had been conducted by using CBA with different layer in the concrete production to improve
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