FORMULATION OF COMPRESSED STABILIZED EARTH BRICK USING BLACK UNCONTROLLED BURNT RICE HUSK ASH AS FULL CEMENT REPLACEMENT

FETRA VENNY RIZA

A thesis submitted in fulfillment of the requirement for the award of the Doctor of Philosophy

Faculty of Civil and Environmental Engineering
Universiti Tun Hussein Onn Malaysia

APRIL 2017
In the name of Allah, the most gracious and the most merciful.

I dedicate this thesis to my beloved family who has been a source of constant support, advices, encouragement, motivation, and love through all this journey.
ACKNOWLEDGEMENT

Alhamdulillah and praise to Allah The Almighty who gave me the strength in completion of this thesis. In the name of Allah, The Most Gracious and The Most Merciful, I would like to take this opportunity to express my gratitude for those helping hands upon this journey.

First of all I would like to thank my supervisor Prof Ismail Abdul Rahman for his patient in supervising, knowledge and enlightened motivation. His guidance was most appreciated through the research and writing this thesis. I was lucky enough to have him as my mentor.

I also extend my gratitude to all technicians that provided the best assistance and cooperation in my research in the laboratories. Also my special appreciation goes to UTHM for granted me the international scholarship which help financial aspect in my research.

Last but not least, I would like to thank all my family, my late mother and father for their understanding and continuous support in putting up with the convenience when I was engaged in finishing my thesis. Especially I owe a considerable debt of gratitude to my husband Josef Hadipramana for his forbearance and remain patient amidst the hardship of this long journey.
ABSTRACT

Black uncontrolled burnt Rice Husk Ash (RHA) obtained from the boiler of rice mill is a waste product which usually causing air and water pollution. As a waste, RHA has very little value and commercial use. Hence this study examined the pozzolanic potential of RHA as a cement replacement in the Compressed Stabilized Earth Brick (CSEB) production. This is an experiment-based study that characterized the raw materials used to produce CSEB samples. In the characterization of raw materials, the XRD analysis found that the burning temperature of the RHA in the rice mill boiler was around 700-800°C. Pozzolanic assessments on the RHA found that it possesses pozzolanic characteristic within, and conformed to ASTM C 618 – 03. Besides that, this study has also managed to develop a new method of determining the pozzolanicity of RHA using electrical resistivity approach which is more practical than Luxan conductivity method. In term of pozzolanic conductivity, it was found that the RHA has a value of 0.47 mS/cm which indicates that the RHA has attained good pozzolanic conductivity. In CSEB samples production, two sets of soils were used which are laterite and clay, and two curing methods that are under tarpaulin sheet and in the curing chamber for 7, 14 and 28 days. CSEB samples used mix ratio of 1:8:2 in proportion binder: soil: sand with 15% water by weight by using 20, 40, 60 and 80% RHA ratio. The samples size of the bricks used is 100 x 50 x 30 mm which is based on Harrison’s brick factor ratio. All samples tested for compressive strength complied with BS 5628-1:2005 for common brick. For water absorption test, all CSEB samples satisfied the ASTM C-62 for normal weather, however only some percentage of the samples passed for moderate and severe weather. Hence this study has verified the hypothesis that waste uncontrolled burnt RHA from the rice mill possessed pozzolanic characteristic which can act as a binder when mix with lime in producing building brick and thus, producing affordable and sustainable building materials for housing project.
ABSTRAK

Abu sekam padi (ASP) hitam daripada sisa pembakaran yang tidak terkawal yang diperolehi daripada dandang di kilang beras adalah merupakan bahan buangan yang selalunya menyebabkan pencemaran udara dan air. Sebagai bahan buangan, ASP mempunyai nilai dan kegunaan komersial yang sangat sedikit. Oleh itu kajian ini meneliti potensi pozolanic dari ASP sebagai pengganti simen dalam penghasilan bata stabil termampat (BST). Ini adalah suatu kajian yang berdasarkan percubaan yang mencirikan bahan mentah yang digunakan untuk penghasilan BST. Didalam pencirian bahan mentah, analisis XRD mendapati bahawa suhu pembakaran SAP di dalam dandang kilang beras sekitar 700-800°C. Penilaian pozolanic pada ASP menemukan bahawa ianya mempunyai ciri-ciri pozolanic dan mematuhi ASTM C 618 – 03. Selain itu, kajian ini juga telah berjaya membangunkan suatu kaedah baru dalam menentukan pozolanicity dari ASP menggunakan pendekatan kerintangan elektrik yang mana ianya lebih praktikal daripada kaedah kekonduksian Luxan. Di dalam terma kekonduksian pozolanic, ditemukan bahawa ASP yang mempunyai nilai 0.47 mS/cm menunjukkan kekonduksian pozolanic yang baik. Dalam penghasilan sampel BST, dua jenis tanah digunakan yaitu laterit dan tanah liat, dan dua kaedah pengawetan diaplikasikan iaitu pengawetan di bawah helaian terpaulin dan dalam kebuk pengawetan selama 7, 14 dan 28 hari. Sampel BST menggunakan nisbah campuran 1: 8: 2 berkadar pengikat: tanah: pasir sebanyak 15% air mengikut berat dengan menggunakan 20, 40, 60 dan 80% nisbah ASP. Ukuran sampel bata yang digunakan adalah 100 x 50 x 30 mm yang mana adalah berdasarkan pada faktor nisbah bata Harrison. Semua sampel yang diuji kekuatan mampatannya mematuhi BS 5628-1:2005 untuk bata biasa. Untuk uji penyerapan air, semua sampel BST memenuhi ASTM C-62 untuk cuaca normal, bagaimanapun hanya beberapa peratus dari sampel yang diluluskan untuk cuaca yang sederhana dan teruk. Oleh itu kajian ini mengesahkan hipotesis bahawa ASP daripada sisa pembakaran yang tidak terkawal mempunyai ciri-ciri pozolanic yang dapat berfungsi sebagai pengikat jika dicampurkan dengan kapur dalam penghasilan bata bahan binaan dan dengan itu menghasilkan bahan-bahan binaan yang murah dan mampun untuk projek perumahan.
# TABLE OF CONTENT

<table>
<thead>
<tr>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>TITLE</td>
<td>i</td>
</tr>
<tr>
<td>DECLARATION</td>
<td>ii</td>
</tr>
<tr>
<td>DEDICATION</td>
<td>iii</td>
</tr>
<tr>
<td>ACKNOWLEDGEMENT</td>
<td>iv</td>
</tr>
<tr>
<td>ABSTRACT</td>
<td>v</td>
</tr>
<tr>
<td>ABSTRAK</td>
<td>vi</td>
</tr>
<tr>
<td>TABLE OF CONTENT</td>
<td>vii</td>
</tr>
<tr>
<td>LIST OF TABLES</td>
<td>xii</td>
</tr>
<tr>
<td>LIST OF FIGURES</td>
<td>xiv</td>
</tr>
<tr>
<td>LIST OF SYMBOLS AND ABREVIATION</td>
<td>xix</td>
</tr>
<tr>
<td>LIST OF UNIT AND CONVERSION</td>
<td>xx</td>
</tr>
<tr>
<td>LIST OF APPENDICES</td>
<td>xxi</td>
</tr>
</tbody>
</table>

**CHAPTER 1** INTRODUCTION  
1.1 Background  
1.2 Problem Statement  
1.3 Aim and Objectives  
1.4 Scope of study  
1.5 Thesis Organization  

**CHAPTER 2** LITERATURE REVIEW  
2.1 Introduction  
2.2 Compressed Stabilized Earth Brick (CSEB)  
2.3 Compositon of CSEB  
2.3.1 Soil  
2.3.1.1 Clay  
2.3.1.2 Laterite  
2.3.2 Stabilizers  
2.3.2.1 Cement
<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.3.2.2 Lime</td>
<td>16</td>
</tr>
<tr>
<td>2.4 Properties of CSEB</td>
<td>18</td>
</tr>
<tr>
<td>2.4.1 Density</td>
<td>18</td>
</tr>
<tr>
<td>2.4.2 Water Absorption and Moisture Content</td>
<td>18</td>
</tr>
<tr>
<td>2.4.3 Strength</td>
<td>20</td>
</tr>
<tr>
<td>2.4.4 Durability</td>
<td>22</td>
</tr>
<tr>
<td>2.4.5 Thermal Value</td>
<td>23</td>
</tr>
<tr>
<td>2.4.6 Carbon Emission and Embodied Energy</td>
<td>24</td>
</tr>
<tr>
<td>2.5 Production of CSEB</td>
<td>25</td>
</tr>
<tr>
<td>2.5.1 Casting</td>
<td>25</td>
</tr>
<tr>
<td>2.5.2 Curing Process</td>
<td>27</td>
</tr>
<tr>
<td>2.6 Application of CSEB</td>
<td>27</td>
</tr>
<tr>
<td>2.7 RHA as an Alternative Stabilizer</td>
<td>30</td>
</tr>
<tr>
<td>2.7.1 Physical Properties</td>
<td>34</td>
</tr>
<tr>
<td>2.7.2 Chemical Properties</td>
<td>35</td>
</tr>
<tr>
<td>2.7.3 Pozzolanic Reaction</td>
<td>37</td>
</tr>
<tr>
<td>2.7.4 Pozzolanic Reactivity</td>
<td>39</td>
</tr>
<tr>
<td>2.8 Statistical Method</td>
<td>41</td>
</tr>
<tr>
<td>2.9 Summary</td>
<td>44</td>
</tr>
<tr>
<td>CHAPTER 3 RESEARCH METHODOLOGY</td>
<td>47</td>
</tr>
<tr>
<td>3.1 Introduction</td>
<td>47</td>
</tr>
<tr>
<td>3.2 Flowchart or Research Process</td>
<td>47</td>
</tr>
<tr>
<td>3.3 Material Preparation</td>
<td>49</td>
</tr>
<tr>
<td>3.3.1 Soil</td>
<td>49</td>
</tr>
<tr>
<td>3.3.1.1 Laterite</td>
<td>50</td>
</tr>
<tr>
<td>3.3.1.2 Clay</td>
<td>50</td>
</tr>
<tr>
<td>3.3.2 Cement</td>
<td>51</td>
</tr>
<tr>
<td>3.3.3 Lime</td>
<td>51</td>
</tr>
<tr>
<td>3.3.4 Sand</td>
<td>51</td>
</tr>
<tr>
<td>3.3.5 Water</td>
<td>52</td>
</tr>
<tr>
<td>3.3.6 Rice Husk and Rice Husk Ash (RHA)</td>
<td>52</td>
</tr>
<tr>
<td>3.4 CSEB Mix Proportion</td>
<td>55</td>
</tr>
<tr>
<td>3.5 Preparation of CSEB Specimen Procedure</td>
<td>57</td>
</tr>
</tbody>
</table>
3.6 Curing Method .......................... 58
3.7 Material Testing Procedure .......... 60
3.7.1 Soil Classification ..................... 60
3.7.2 Specific Gravity ......................... 60
3.7.3 Particle Size Distribution .......... 62
3.7.4 Moisture Content ....................... 63
3.7.5 Loss on Ignition (LOI) ................. 63
3.7.6 Thermogravimetric Analysis (TGA) . 64
3.7.7 X-Ray Fluorescence (XRF) .......... 65
3.7.8 X-Ray Diffraction (XRD) .......... 67
3.7.9 Fourier Transform Infra Red Spectroscopy (FTIR) 69
3.7.10 Microstructure ......................... 69
3.7.11 Pozzolanic Reactivity ................. 71
3.7.11.1 Conductivity Method ............... 71
3.7.11.2 New Developed Resistivity Method 73
3.8 CSEB Compression Test .................. 75
3.9 CSEB Water Absorption .................. 76
3.10 Assessing the Experimental Data ....... 77
3.10 Summary ................................ 79

CHAPTER 4 CHARACTERISTIC AND POZZOLANICITY OF RICE HUSK ASH
4.1 Introduction ............................... 80
4.2 Physical Properties of RHA ............. 80
4.2.1 Physical Appearance of RHA .......... 83
4.2.2 Moisture Content of RHA ............. 84
4.2.3 Loss on Ignition (LOI) of RHA ......... 84
4.2.4 Thermogravimetric Analysis (TGA) of RHA 86
4.2.5 X-Ray Fluorescence (XRF) of RHA .... 87
4.2.6 X-Ray Diffraction (XRD) of RHA .... 88
4.2.7 Amorphous Content of RHA .......... 91
4.2.8 Fourier Transform Infra Red Spectroscopy (FTIR) of RHA 95
4.3 Microstructure Properties of RHA ...... 98
CHAPTER 5 APPLICATION OF WASTE RICE HUSK ASH IN COMPRESSED STABILIZED EARTH BRICK

5.1 Introduction

5.2 Material Characterization in CSEB Production
  5.2.1 Bulk Density and Specific gravity
  85.2.2 Particle Size Distribution
  5.2.3 Soil Characterization
  5.2.4 CSEB Dimension and Density
  5.2.5 Determination of Mix Proportion
  5.2.6 Curing CSEB

5.3 CSEB Compressive Strength Performance
  5.3.1 Influence of Soil Types
  5.3.2 Influence of Curing Method

5.4 CSEB Water Absorption Performance
  5.4.1 Discussion on Influence of Soil Types
  5.4.2 Influence of Curing Method

5.5 CSEB Microstructure

5.6 Prediction of CSEB Compressive Strength and Water Absorption
  5.7 Equation for Practical Application

5.8 Summary

CHAPTER 6 CONCLUSIONS AND RECOMMENDATIONS

6.1 Introduction

6.2 Conclusion
  6.2.1 Investigation the Pozzolanic Potential of Waste RHA
6.2.2 Exploration of Resistivity Method for Measuring the RHA Pozzolanicity 160
6.2.3 Determination the Optimum CSEB Mix Proportion 161
6.2.4 Developed of Mathematical Equation for CSEB Compressive Strength and Water Absorption 162

6.3 Recommendations 163

REFERENCES 164
APPENDIX A 180
APPENDIX B 184
APPENDIX C 188
APPENDIX D 190
APPENDIX E 192
APPENDIX F 194
APPENDIX G 196
APPENDIX H 198
APPENDIX I 200
APPENDIX J 202
APPENDIX K 204
APPENDIX L 205
VITA 209
LIST OF TABLES

2.1 Suggested lime content (%) by Ingles and Metcalf. 17
2.2 Comparison of ash and silica content from various plants. 32
2.3 RHA Properties from various researchers. 35
2.4 Chemical composition of RHA from various researchers. 36
3.1 Mix proportion of CSEB. 56
4.1 Moisture content of RHA. 84
4.2 LOI of RHA. 85
4.3 Weight change and % different weight with LOI. 86
4.4 Chemical content percentage of controlled and uncontrolled burnt RHA. 89
4.5 Compound of each RHA samples. 91
4.6 Group Wavenumbers of Silica. 96
4.7 Conductivity values of RHA by Luxan method. 111
4.8 Resistivity values of RHA by resistivity method. 114
4.9 Data entry for comparison resistivity and conductivity method. 115
4.10 Correlation coefficient from resistivity and conductivity method. 116
4.11 Descriptive statistical analysis from resistivity and conductivity method. 116
4.12 Regression analysis of resistivity and conductivity method. 117
4.13 Pozzolanic classification of new resistivity method. 118
5.1 Bulk density of materials. 121
5.2 Particle size analysis of binders. 124
5.3 Soil chemical composition percentage. 125
5.4 Atterbeg limits of laterite and clay. 126
5.5 CSEB density. 127
5.6 Compressive strength in MPa. 135
5.7 Water Absorption of CSEB. 135
5.8 Types of CSEB

5.9 Experimental data of CSEB 1.

5.10 Experiment and prediction value of compressive strength and water absorption of CSEB 1.

5.11 Coefficient of determinant ($R^2$) of equations model

5.12 T-test value of CSEB 1

5.13 t-statistic of compressive strength CSEB 1.

5.14 t-statistic of water absorption CSEB 1.

5.15 Experimental and Predicted Compressive Strength Equation 5.1.

5.16 Experimental and Predicted Water Absorption Equation 5.2.

5.17 Coefficient of Variation.

5.18 Equations for predicted compressive strength.

5.19 Equations for predicted compressive strength.

6.1 Pozzolanic potential of waste RHA.

6.2 Comparison Luxan Method and New Develop Resistivity

6.3 Method.

6.4 Proposed pozzolanic value classification.

6.5 Conformation of CSEB types to ASTM C-62.

Predicted Equation for CSEB.
### LIST OF FIGURES

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1</td>
<td>Clay distribution map in Peninsular Malaysia.</td>
<td>12</td>
</tr>
<tr>
<td>2.2</td>
<td>Map of laterite deposit around the world.</td>
<td>13</td>
</tr>
<tr>
<td>2.3</td>
<td>Distribution of laterite soil in Peninsula, Malaysia.</td>
<td>14</td>
</tr>
<tr>
<td>2.4</td>
<td>Air moisture absorbed from several materials.</td>
<td>20</td>
</tr>
<tr>
<td>2.5</td>
<td>Values of ‘factory gate’ embodied carbon for masonry materials.</td>
<td>24</td>
</tr>
<tr>
<td>2.6</td>
<td>South Africa, Simunye Project Demonstration house built in 12 days.</td>
<td>28</td>
</tr>
<tr>
<td>2.7</td>
<td>Shri Karneshwar Nataraja Temple in Tamil Nadu, India.</td>
<td>28</td>
</tr>
<tr>
<td>2.8</td>
<td>Vaulted structure for the resort at Sandele.</td>
<td>29</td>
</tr>
<tr>
<td>2.9</td>
<td>Water tank with CESB, built on round blocks 290.</td>
<td>29</td>
</tr>
<tr>
<td>2.10</td>
<td>Earthquake resistant house built at Istanbul, Turkey.</td>
<td>29</td>
</tr>
<tr>
<td>2.11</td>
<td>Al Medy Mosque built in 7 weeks at Riyadh, Saudi Arabia.</td>
<td>30</td>
</tr>
<tr>
<td>2.12</td>
<td>Dejbjerg Iron Age Museum, built in 1998 Ringkøbing-Skjern, Denmark.</td>
<td>30</td>
</tr>
<tr>
<td>2.13</td>
<td>World Rice Production up to 2011.</td>
<td>31</td>
</tr>
<tr>
<td>2.14</td>
<td>Malaysia rice production estimation.</td>
<td>31</td>
</tr>
<tr>
<td>2.15</td>
<td>Schematic of RHA production.</td>
<td>33</td>
</tr>
<tr>
<td>2.16</td>
<td>Lime cycle.</td>
<td>38</td>
</tr>
<tr>
<td>3.1</td>
<td>Flow chart of the experiment in this study.</td>
<td>48</td>
</tr>
<tr>
<td>3.2</td>
<td>Laterite soil before and after crushed.</td>
<td>50</td>
</tr>
<tr>
<td>3.3</td>
<td>Dried clay lump before crushed.</td>
<td>50</td>
</tr>
<tr>
<td>3.4</td>
<td>Hydrated Lime.</td>
<td>51</td>
</tr>
<tr>
<td>3.5</td>
<td>Sieved sand.</td>
<td>52</td>
</tr>
<tr>
<td>3.6</td>
<td>Water pH is checked with pH meter.</td>
<td>52</td>
</tr>
<tr>
<td>3.7</td>
<td>Rice husk and uncontrolled burnt RHA from rice milling boiler.</td>
<td>53</td>
</tr>
<tr>
<td>3.8</td>
<td>Kiln Furnace with air funnel.</td>
<td>53</td>
</tr>
</tbody>
</table>
3.9 Opening of the furnace. 54
3.10 RHA after combustion. 55
3.11 CSEB after sampling. 56
3.12 Sequence of preparing CSEB specimen. 57
3.13 CSEB cured under tarpaulin. 59
3.14 Spraying CSEB before covered by tarpaulin. 59
3.15 Curing chamber 59
3.16 Desiccator. 61
3.17 Particle size Analyzer CILAS 1180 to determine the particle size distribution of materials. 62
3.18 Container of particle size analyzer filled with distilled water. 62
3.19 TGA equipment. 64
3.20 XRF Machine. 65
3.21 Die set to cast the sample pellet for XRF. 66
3.22 Pellet sample was given compression pressure 80 kN. 66
3.23 Sample pellets for XRF test. 66
3.24 XRD Bruker D8 Advance. 67
3.25 Perkin Elmer Spectrum 100 FT-IR Spectrometer. 68
3.26 JEOL JSM-7600F FESEM. 69
3.27 JEOL JFC-1600 Auto Fine Coater. 70
3.28 Laboratory reagent Ca(OH)₂. 71
3.29 Conductivity meter Hach Sension 5. 71
3.30 Digital stirring hot plate Corning PC-420D. 72
3.31 Magnetic bar stirrer. 72
3.32 Schematic diagram of modified soil box for resistivity measurement. 73
3.33 Modified soil box resistivity test equipment. 74
3.34 Steel cap was applied above the brick to ensure uniform load was distributed evenly. 76
3.35 The bricks were submerged in the cold water for 24 hours. 77
4.1 Whitish grey RHA as a result form complete combustion with air circulation. 81
4.2 Blackish grey RHA as a result from incomplete combustion 81
without air circulation.

4.3 Waste RHA from rice milling.

4.4 TGA graph of RHA 400°C.

4.5 Comparison of X-ray diffraction patterns of all RHA samples.

4.6 RHA XRD graph from the work of Serra et al (2015).

4.7 Crystallography of fully crystalline iron powder

4.8 Crystallography of fully amorphous glass.

4.9 X-ray diffraction graph classification of crystalline, amorphous and monatomic gas.

4.10 RHA burnt at 400°C (99.3% amorphous, 0.7% crystalline).

4.11 Amorphous content of controlled and uncontrolled burnt RHA.

4.12 FTIR spectrum of controlled and uncontrolled burnt RHA.


4.14 IR correlation chart of SiO 2 adapted from National Institute of Standards and Technology (NIST).

4.15 A fraction of single raw rice husk.

4.16 Outer epidermis of rice husk.

4.17 Inner epidermis of rice husk.

4.18 In between outer and inner epidermis of rice husk.

4.19 Porous properties is observed in rice husk.

4.20 RHA 400 at 1000 magnification.

4.21 RHA 400 at 10000 magnifications.

4.22 RHA 500 at 1000 magnification.

4.23 RHA 500 at 5000 magnification.

4.24 RHA 600 at 2000 magnification.

4.25 RHA 600 at 10000 magnification.

4.26 RHA 700 at 1000 magnification.

4.27 RHA 700 at 5000 magnification.

4.28 RHA 800 at 1000 magnification.

4.29 RHA 800 at 10000 magnification.

4.30 RHA 900 at 1000 magnification.

4.31 RHA 900 at 10,000 magnification

4.32 RHA 1000 at 1000 magnification.
4.33 RHA 1000 at 10000 magnification.  
4.34 RHA Muar, Malaysia at 700 magnification.  
4.35 RHA Muar, Malaysia at 5000 magnification.  
4.36 Pozzolanic reactivity with conductivity method.  
4.37 Comparison conductivity and resistivity method after compensate.

5.1 Cement particle size distribution graph.  
5.2 Hydrated lime particle size distribution graph.  
5.3 Uncontrolled burnt RHA passed 200 µm sieve particle size distribution graph.  
5.4 Uncontrolled burnt ground RHA particle size distribution graph.  
5.5 RHA Muar as received (a) and RHA after sieved (b).  
5.6 Particle size distribution graph of laterite and clay soil.  
5.7 Casagrande Chart for laterite and clay soil.  
5.8 Compressive strength of laterite CSEB with tarpaulin curing.  
5.9 Compressive strength of clay CSEB with tarpaulin curing.  
5.10 Compressive strength of bricks from laterite CSEB with curing chamber.  
5.11 Compressive strength of bricks from clay CSEB with curing chamber.  
5.12 Relationship between compressive strength and RHA content.  
5.13 Relative increase of compressive strength with cement content for different group of soil.  
5.14 Water absorption of laterite CSEB with tarpaulin curing.  
5.15 Water absorption of clay CSEB with tarpaulin curing.  
5.16 Water absorption of laterite CSEB with curing chamber.  
5.17 Water absorption of clay CSEB with curing chamber.  
5.18 Relationship between water absorption and RHA content.  
5.19 CSEB of control laterite under 5000x magnification.  
5.20 Schematic view of the interfacial transition zone around an aggregate particle.  
5.21 CSEB of control clay under 5000x magnification.
5.22 CSEB of laterite 20% under 5000x magnification. 142
5.23 CSEB of laterite 40% under 5000x magnification. 143
5.24 CSEB of laterite 60% under 5000x magnification. 143
5.25 CSEB of laterite 80% under 5000x magnification. 144
5.26 CSEB of clay 20% under 5000x magnification. 144
5.27 CSEB of clay 20% under 5000x magnification. 145
5.28 CSEB of clay 60% under 5000x magnification. 145
5.29 CSEB of clay 80% under 5000x magnification. 146
5.30 Guideline graph RHA content vs Compressive strength. 156
5.31 Guideline graph RHA content vs Water absorption. 156
LIST OF SYMBOLS AND ABBREVIATION

\begin{align*}
\text{Al}_2\text{O}_3 & \quad = \text{Aluminium oxide} \\
\text{CaO} & \quad = \text{Calcium oxide} \\
\text{CO}_2 & \quad = \text{Carbon dioxide} \\
\text{CSEB} & \quad = \text{Compressed Stabilized Earth Brick} \\
\text{CV} & \quad = \text{Coefficient of variation} \\
\text{FTIR} & \quad = \text{Fourier Transform Infra-Red} \\
\text{Fe}_2\text{O}_3 & \quad = \text{Iron oxide} \\
\text{K}_2\text{O} & \quad = \text{Potassium oxide} \\
\text{MgO} & \quad = \text{Magnesium oxide} \\
\text{Na}_2\text{O} & \quad = \text{Sodium oxide} \\
\Omega & \quad = \text{Electrical resistance (ohm)} \\
\text{OPC} & \quad = \text{Ordinary Portland Cement} \\
\text{PSD} & \quad = \text{Particle Size Distribution} \\
R^2 & \quad = \text{Coefficient of Determinant} \\
\text{RHA} & \quad = \text{Rice Husk Ash} \\
\rho & \quad = \text{Electrical resistivity (ohm.meter)} \\
\sigma (\text{sigma}) & \quad = \text{Electrical conductivity \{siemens per metre (S/m)\}} \\
\text{SiO}_2 & \quad = \text{Silicon dioxide} \\
\text{SO}_3 & \quad = \text{Sulfur trioxide} \\
\text{TGA} & \quad = \text{Thermogravimetric Analysis} \\
\text{TiO}_2 & \quad = \text{Titanium dioxide} \\
\text{XRD} & \quad = \text{X-Ray Diffraction} \\
\text{XRF} & \quad = \text{X-Ray Fluorescence}
\end{align*}
LIST OF UNITS AND CONVERSION

<table>
<thead>
<tr>
<th>Unit</th>
<th>Conversion</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 MPa</td>
<td>1 N/mm²</td>
</tr>
<tr>
<td>1 Nm</td>
<td>1 Joule</td>
</tr>
<tr>
<td>1 N</td>
<td>1 Kg.m/s²</td>
</tr>
<tr>
<td>1 sec</td>
<td>1000 µs</td>
</tr>
<tr>
<td>Counts</td>
<td>In terms of EDS – Unit is quantitative element or chemical characterization.</td>
</tr>
<tr>
<td>KeV</td>
<td>Kilo Electron Volts</td>
</tr>
</tbody>
</table>
## LIST OF APPENDICES

<table>
<thead>
<tr>
<th>APPENDIX</th>
<th>TITLE</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>X-Ray Diffraction (XRD)</td>
</tr>
<tr>
<td>B</td>
<td>Amorphous content of RHA</td>
</tr>
<tr>
<td>C</td>
<td>Multiple Linear Regression Analysis for Laterite Terpaulin Compressive Strength</td>
</tr>
<tr>
<td>D</td>
<td>Multiple Linear Regression Analysis for Laterite Curing Chamber Compressive Strength</td>
</tr>
<tr>
<td>E</td>
<td>Multiple Linear Regression Analysis for Clay Terpaulin Compressive Strength</td>
</tr>
<tr>
<td>F</td>
<td>Multiple Linear Regression Analysis for Clay Curing Chamber Compressive Strength</td>
</tr>
<tr>
<td>G</td>
<td>Multiple Linear Regression Analysis for Laterite Terpaulin Water Absorption</td>
</tr>
<tr>
<td>H</td>
<td>Multiple Linear Regression Analysis for Laterite Curing Chamber Water Absorption</td>
</tr>
<tr>
<td>I</td>
<td>Multiple Linear Regression Analysis for Clay Terpaulin Water Absorption</td>
</tr>
<tr>
<td>J</td>
<td>Multiple Linear Regression Analysis for Clay Curing Chamber Water Absorption</td>
</tr>
<tr>
<td>K</td>
<td>Table t-Distribution</td>
</tr>
<tr>
<td>L</td>
<td>Research Publication</td>
</tr>
<tr>
<td>Type</td>
<td>Page</td>
</tr>
<tr>
<td>--------------------</td>
<td>------</td>
</tr>
<tr>
<td>Book Chapter</td>
<td>205</td>
</tr>
<tr>
<td>Conference Proceedings</td>
<td>205</td>
</tr>
<tr>
<td>Journals</td>
<td>207</td>
</tr>
</tbody>
</table>
CHAPTER 1

INTRODUCTION

1.1 Background

The oldest earth masonry known is sundried/unfired earth bricks made from shaped mud brick (adobe) dating back to before 8000-6000 BC and was found in Turkestan, Russia (Pumpelly, 1908). It was also found in ancient cultures that were scattered from Assyria (ca. 5000 BC), vaults in the Temple of Ramses II at Gourna, Egypt (3200 years ago), the citadel of Bam in Iran (2500 years old), a fortified city in the Draa valley in Morocco (2500 years old), the core of the Sun Pyramid in Teotihuacan, Mexico (300-900 AD), including Great Wall of China (4000 years old) were built from mud brick (Minke, 2006). Unfired earth with the shape of mud brick (adobe) has been used since Mesopotamian era but with the invention of fired bricks make unfired bricks less popular because fired bricks have better strength. However, at the 20th century, engineers found although unfired bricks not as superior as fired bricks in term of strength, its properties can be enhanced by compaction (Oti et al., 2009a). Furthermore, unfired bricks possessed good quality of green and sustainable building material. Thus, unfired brick that was made with compression process called Compressed Stabilized Earth Bricks (CSEB) is the modern descendent of adobe brick from ancient time.

Most of the world populations live in earth material house especially in the hot arid climate and estimated about one half in developing countries (Minke, 2006). The use of earth masonry had been once very popular then declined gradually along with the invention of Portland cement. Although the superiority of cement compare with the earth masonry seems very appealing, later on people realized the negative impact of cement to environment. With the increasing awareness of health and environment, it was realized lately that the use of earth masonry apparently environmentally friendly
with such ability to control temperature and humidity of the building makes it an ideal natural building material (Hall et al., 2012; Minke, 2000).

According to Food and Agriculture Organisation (FAO) of United Nation, Malaysia produced 2.6 million tons of rice in 2014 (FAOstat, 2015). Rice husk will be used for the fuel in the boiler to generate electricity for the mill and approximately 25% of the husk will be converted to rice husk ash (RHA) (Cook et al., 1977). As a by-product from rice mill, the utilization of RHA by the people around the rice mill were very limited that made RHA has very little or no commercial value. Looking at the statistic, 6.5 million tonnes RHA are available to take advantage of. Among the alternative to utilize the RHA is as a material for CSEB. From the past researches regarding RHA, mostly used as complimentary material in sustainable construction (Coutinho, 2003; Tashima et al., 2004). Thus, RHA has big potential as material to produce low cost and green building material out of it and also will benefit many as it can be produced locally by indigenous community where the RHA can be found.

CSEB has many basic properties that made it a relatively green building materials i.e. fire resistant, extremely low embodied energy, hygroscopic (a nature to absorb moisture) environment regulation, good thermal insulation, ease of reuse/recycling, vapour permeable wall construction (Sutton et al., 2011). As earth masonry, soil is the main ingredient that play important role in CSEB. The soil types used will affect the selection of correct stabilizer such as ordinary Portland cements (OPC) that usually used as a primary binder (Bahar et al., 2004; Guettala et al., 2006; Jayasinghe & Mallawaarachchi, 2009; Oti et al., 2009a; Oti et al., 2009b, 2009c; Walker, 1995, 1999, 2004; Walker & Stace, 1996), although other binders which create cementitious effect are often be used as substitution for stabilizer such as lime, gypsum, pulverized fly ash (PFA) (Freidin & Erell, 1995; Kumar, 2002), ground granulated blast furnace (GGBS) (Freidin & Erell, 1995; Kumar, 2002; Oti et al., 2009a; Oti et al., 2009b, 2009c) and many more.

With modern earth building movement is getting more popularity like in Africa, India and Thailand and start spreading to other country (Chen, 2009; Morris & Blier, 2004), adobe brick (brick made with sun-dried clay without compaction) and CSEB making their way to be sustainable yet durable building material, with adobe brick as the most popular technique. CSEB on the other hand, quite pricey for average people in developing country since the machinery seems like expensive investment
that will only be used once. While in the west, labour’s cost quite pricey (Delgado & Guerrero, 2006), which is why mechanization is more preferable in practical sustainability and CSEB is more popular choice. CSEB construction is economically viable option that can compete with conventional home building methods.

Usually CSEB using Portland cement as stabilizer for it has higher strength. But the controversy around how high carbon emission contribution caused by cement production makes CSEB now seems less sustainable. On the other hand, rice husk ash (RHA) as a by-product from rice milling is an important source of silica and have confirmed to have pozzolanic properties which means it will create cementitious materials if finely divided and when combine with calcium hydroxide (Ca(OH)₂) at ordinary temperature with the presence of moisture (Al-Khalaf & Yousif, 1984; Cook et al., 1977; Hani et al., 2009; Hassan & Mustapha, 2007; Ismail & Waliuddin, 1996; James & Rao, 1986b; Jauberthie et al., 2000; Jha & Gill, 2006; Laksmono, 2002; Ramezanianpour et al., 2009; Sensale, 2006; Yalçin & Seviç, 2001). Furthermore, pozzolanic materials have filling role that can reduce water demand and increase cement strength (Coutinho, 2003; Xiaoyu, 1996). As a pozzolan, RHA cannot produce cementitious material by itself unless it combines with calcium hydroxide. Therefore, in this project, lime will be used together with uncontrolled burnt RHA to completely replace cement as a stabilizer.

1.2 Problem Statement

Two third of the world populations which mostly in developing and under developed countries live in earth material house especially in the hot arid climate (Minke, 2006). Hence there is a need of cheap, locally available and sustainable construction material for the housing. Many researches were carried out related to this issue and most of the researches identified wastes generated locally were used as components for building material.

Malaysia produced about 2.6 million tonnes rice in 2014 (FAOstat, 2015) and the wastes is rice husk which is abundantly available in Malaysia. This contributed to significant amount of RHA waste generated from rice mill. Usually, this RHA waste causing environmental and disposal problems due to not enough alternatives to use and take advantage of it (Ramezanianpour et al., 2009). Theoretically, RHA as agricultural
waste is suitable as pozzolanic source by virtue of it contains high amount of silica. (Yalçın & Sevinç, 2001). RHA which contains high percentage of silica, possessed pozzolanic properties that creates cementitious materials when combine with calcium hydroxide (Ca(OH)2) solution at ordinary temperature (Sensale, 2006).

Most of the studies used the controlled burnt RHA in the production of construction materials (Lertsatitthanakorn et al., 2009; Nilantha et al., 2010; Sensale et al., 2008; Tashima et al., 2004; Zain et al., 2011) rather than utilized the uncontrolled burnt RHA. Moreover these research works were related to the application of RHA in concrete production (Chao-Lung et al., 2011; Coutinho, 2003; Tashima et al., 2004; Xiaoyu, 1996; Zhang et al., 1996) and however its application in brick production was very limited. Lengthen to these, majority of researches utilized RHA as partial cement replacement in the concrete mix and few has tried to use RHA in the brick production but still used as partial cement replacement (Lertsatitthanakorn et al., 2009).

Commonly, most commercial brick is fired brick which contributes to carbon emission resulted to pollution. As contrast, unfired earth brick is more sustainable as it uses cement as a binder without need burning in the kiln. Then, if the unfired earth brick can be made locally with in situ material, more people will have access to affordable and environmentally friendly building material. Since uncontrolled burnt RHA is abundantly available and considered as waste from Malaysia rice mill, hence, this study intended to investigate the potential usage of this uncontrolled burnt RHA as full cement replacement in the production of CSEB even though the uncontrolled burnt RHA generated from rice milling combustion poses poor pozzolanic reactivity(Wansom et al., 2009). The outcome of this study will contribute to the brick which is cheaper and environmentally friendly production without involving burning process.

1.3 Aim and Objectives

The aim of this research is to formulate compressed stabilized earth brick (CSEB) using waste RHA with hydrated lime as full cement replacement as a binder. To achieve this aim, the following objectives were derived:

i. Investigate the pozzolanicity potential of waste RHA.
ii. Explore electrical resistivity method for measuring the pozzolanicity and comparably assessed the value with electrical conductivity method (Luxan method).

iii. Determine the optimum CSEB mix proportion.

iv. Examine the effect of curing method with curing chamber and under tarpaulin sheet.

v. Develop mathematical equation for CSEB compressive strength and water absorption

1.4 Scope of Study

This study compared the RHA from rice mill that was burnt under uncontrolled burning condition in the boiler with the RHA under controlled burning in the laboratory. RHA under controlled burning in the laboratory at first stage used several temperatures at 400°C, 500°C, 600°C, 700°C, 800°C, 900°C and 1000°C and one optimal temperature will be chosen to be compared with RHA from rice mill.

The soils used in this study are limited to locally available soil, there are clay and laterite soil. Among the purpose of this study is to produce cheap and affordable CSEB. RHA with lime used as a binder in CSEB production. Although hydraulic lime has better properties than hydrated lime but since hydrated lime that was cheaper than hydraulic lime, hence this study used the hydrated lime.

Brick dimension used is a scale down size from the average commercial brick found in the market by halved the common brick size available in the market, which is from 200 x 100 x 60 mm to 100 x 50 x 30 mm. According to Harrison (2010) this dimension has the same ratio with the actual size that makes this size feasible to represent the actual size.

Curing method was done in the open air under the assumption of the average relative humidity in Malaysia throughout one year that is 80±5%. Curing chamber was set at temperature 20°C and humidity at 80%. Curing was done for 7, 14 and 28 days as with the compressive strength and water absorption test.

The result of compressive strength and water absorption test then was analysed with analysis of variant (ANOVA) to develop mathematical equation and from that create a simple graph for practical application in producing CSEB.
1.5 Thesis Organization

This thesis will comprise the following section.

Chapter 1 introduces the background of research, problems statement, aim and objectives of the research, scope of work and significance of the study.

Chapter 2 comes up with the literature review on compressed earth brick, history of bricks, bricks production and elaborate the RHA as a source of silica, pozzolanic materials, lime reaction with rice husk ash and the findings from previous study.

Chapter 3 explain the methodology used in this study, from the materials preparation, materials testing, brick production, curing method, and brick testing.

Chapter 4 delivers the information about RHA pozzolanicity in this study from the aspect of mechanical, physical and chemical properties.

Chapter 5 administers the formulation of CSEB from raw materials, mix proportion, brick production, curing method, CSEB testing, brick microstructure properties, relationship between data statistical analysis and mathematical equation model.

Chapter 6 concludes all the work done and provides recommendation for future study.
CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The use of earth masonry can be traced back since before 7500 BC in the shape of mud brick or adobe with the sun-dried technique. At 4500 BC, trace of fired brick was found in Indus Valley cities. Circa 500-300 BC, The Greek has had the knowledge to mix pozzolan with lime mortars in order to make it hydraulic, by adding highly siliceous, volcanic Santorin earth (Idorn, 1997). However, application of pozzolan in concrete shows that the Roman is the first to invent hydraulic mortars as a mixture in concrete around 25 BC in a famous book written by Vitruvius (1932), De Architectura - Book II. In Chapter VI of the book, he has written “Est etiam genus pulveris quod efficit naturaliter res admirandas” which means ‘there is also a kind of powder, which due to its nature gives excellent result’ to the strength and durability of the concrete. The powder refers to pozzolanic material which turned out to produce better concrete compared than that of pure lime in aspect of strength and durability with support of superior workmanship.

However, the superiority of pozzolan in Roman concrete only used during Roman Empire and slowly faded away along with the collapse of the empire. Unfortunately, the Roman concrete leave no mix proportion and limitation of pozzolan source which exclusively available in Rome back then and the decreasing of workmanship skill were some factors that make Roman concrete forgotten. Hence the knowledge of this remarkable concrete also disappeared.

With the fall of Roman, earth masonry application still becomes the main building technique that used across the globe until the invention of Portland cement, the use of earth masonry started to replace by modern concrete. The cement production is growing so fast as the economy emerge and concrete now become the
most consume material in earth after water (Hewlett, 1998). However, with one third (Morton, 2008) to one half (Morris & Blier, 2004) of world population still lives in the low budget earthen architecture mostly in developing country, the use of earth masonry will regain its popularity once more. And CEB as one of earth masonry application offers many benefits and superiority than concrete in sustainable and environmental friendly point of view. Unluckily, mostly commercial CEB in the market now use cement as stabilizer makes it less green with the issue of carbon emission.

As the people awareness of the environmental issues increased, the cement production that releases carbon dioxide in high amount, which in turn creates air pollution that appear to be hazardous to the human health, has become great concern among environmentalist. Therefore, the use of earth masonry that incorporated abundantly available agricultural waste that has pozzolanic properties and lime, which could absorb CO$_2$ emission in its reverse chemical reaction as stabilizer seems appealing.

Aside as the additive for cement production, researchers have made attempt to substitute cement with pozzolan. However, with the natural pozzolan source restriction, researcher has come out with another source of pozzolan, mostly with by-product materials from the factory or agriculture.

This recent study worked out in the viewing of making the CSEB without cement and substituted it with abundantly available RHA and lime especially in the benefit of cost effectiveness and environmental issues concerning waste materials disposal and reduction of carbon dioxide emission.

Furthermore, this chapter discussed about multiple materials involved in this study and conjunction with some literacy those undertaken by previous researchers, whether research investigation and standards determined by government agency that had been recognised. So, this research reached alignment between the results of this research with some methods that have been executed and predefined.

### 2.2 Compressed Stabilized Earth Brick (CSEB)

Together with rammed earth and adobe, earth brick is one of the oldest building materials that used widely in the world since the ancient times. CSEB is a modern
type of earth brick that manufactured in a mechanical press, made from a mixture of soil and aggregate (Gesimondo & Postell, 2011). The apparent difference of CSEB from rammed earth is the process to form it by using compaction with pressure. Earth brick is always known as ‘green’ material owing to its thermal properties that ‘breathable’. Its thermal properties let the construction to meet the cooling and heating need of the building. In the winter, earth brick construction will warm up the building while at the summer, its cooling effect will be very useful.

Earth brick also can be used as exterior and interior wall. Earth brick suitable as building materials from arid, semi-arid to tropical climate, although in the wet or rainy climate can make a good use of additional insulation or extended roof overhangs. Earth brick can be left unfinished or finished with plaster or paint. However, the natural lime based finished would be better to allow the wall keeps breathable.

As earth based material, CSEB possessed good sustainability characteristic in broad range criteria. CSEB considered has low environmental impact as building material compared to other earth materials such as fired brick. Advantages of CSEB over fired brick and concrete are:

i. Low embodied energy and carbon emission (Deboucha & Hashim, 2011; Morton, 2008).

ii. Non-toxic and acid rain free. Firing process in fired brick production would release, toxic gas and vapours in the firing process from sulphur content of clay especially sulphur dioxide, fluorides and chlorides (Woolley et al., 2005).

iii. Fire retardant as earthen walls do not burn (Deboucha & Hashim, 2011).

iv. Good sound insulation (Acosta et al., 2010).

v. Fungi and insect resistant. CSEB house provide constant relative humidity that prevent fungus forming (Morton, 2008).

vi. Renewable material. With soil as basic material, CSEB can be reused and reproduced unlike wood or concrete (Morton, 2008).

vii. Energy saving. Owing to the thermal mass properties of CSEB that result in lower heating and cooling requirements thus lower electricity usage for air conditioner in the summer and heater in the winter makes it good thermal
insulation as CSEB wall absorbs moisture and gives it back when it dries (Morton, 2008).

viii. Low waste production and easily dispose of with earth as the primary material (Morton, 2008).

ix. With bamboo or rebar reinforcement, CSEB structures can be built to resist earthquake damage in seismic zones (Kennedy, 2013).

CSEB has been applied recently in the India and Thailand even though in small scale project, also some countries in the Africa adopt CSEB system for the labour cost reason while countries in Europe applied CSEB in the home making usage more to the environmental reason. Density

2.3 Composition of CSEB

Basically, the development of CSEB involved some materials such as soil, sand, and water as the main ingredients (matrix), while binder added to enhance the performance of CSEB. Usually, the binder found in the commercial CSEB is cement, although some researchers incorporated cementitious materials to substitute cement for examples lime, lime-RHA, lime-POFA, lime-fly ash, silica fume-coal ash also can be acted as binders (Basha et al., 2005; Munthar, 2011; Villamizar et al., 2012). However, only cement, lime and RHA as binders will be discussed in this study.

2.3.1 Soil

Soil plays very significant role as a natural building material and its availability in most region of the world is plentiful. Soil is usually obtained directly in the construction site when excavating foundation or basement is excavated. One of the key factors to optimize the soil usage as building material is the selection of correct stabilizer based on the soil used. Therefore, the detail information of the soil used is essential. Soil is classified based on properties such as grain size, Atterberg’s limit etc. Also, the type and percentage of clay mineral present in soil very much affect the binder and strength of the brick.
For the production of CSEB, soil can be classified into two categories, expansive and less expansive soil (Reddy, 2012). Expansive soil is the soil with excessive swelling clay minerals such as montmorillonite, that when come into contact with water cause excessive swelling and shrinkage when drying. Expansive soil best suited with lime stabilizer since lime reacts with expansive clay and form cementitious hydrates of calcium-silicate, calcium-aluminates that responsible for strength development. Less expansive soil like kaolinite and illite do not swell and shrink and best stabilized by cement. In this study, clay and laterite soil will be used because those are locally available soil in Malaysia.

2.3.1.1 Clay

Clay is formed on the earth's surface as a result of the earth crust weathering for a very long time of a rock called Feldspar. Feldspar in igneous rocks breaks down to sedimentary clays mixed with other materials which are blended into clay. This transformation of rocks turned to be clay is a matter of geology and time where erosion takes place. The weathering process of clay formation results in a number of variations in the type of clay.

There are three main groups of clays, there are kaolinite, montmorillonite and illite (Grim, 2010). These clay types are the result in variations in the particle size of a particular deposit and/or the quantity of impurities. Clay that was found near the parent material (granite) called residual or primary clay, usually grainy and has low plasticity or non-plastic. Clay deposits that were found far away from source materials, transported by water, wind and ice called sedimentary or secondary clays, have smaller and more uniform particles, and high plasticity (Velde, 1995). Due to the weather cycle, the clay will continuously be formed. Figure 2.1 shows the map from Malaysian Highway Authority of clay distribution in Peninsular Malaysia.

Clay according to soil engineers refers to particles size smaller than 2 µm (Velde, 1995). Based on study about clays in Peninsular Malaysia it was found out that its specific gravity around 2.42 - 2.65, from XRD test main minerals in clays is quartz and secondary minerals is kaolinite where from XRF test showed that SiO₂ and Al₂O₃ are the main compounds, and SEM test confirmed the presence of

From its plasticity characteristic and properties, clay usually used in construction material such as fired bricks, adobe, rammed earth for wall and floor tile. Also clay naturally impermeable to water that makes it suitable for water construction such as dams (Koçkar et al., 2005). Firing process will change the physical and chemical properties of clay permanently.

Figure 2.1: Clay distribution map in Peninsular Malaysia (Source: Malaysian Highway Authority, 1989).

2.3.1.2 Laterite

Laterite literally means brick, derived from the Latin word ‘later’, first introduced by Francis Buchanan in 1807 (Hamming, 1968; Maignien, 1996; Tardy, 1997) to describe reddish weathered soil with high concentration of iron and aluminium oxides and the distinct characteristics of this soil are the presence of an abundance of sesquioxides and general absence of silica and alkaline earths (Townsend & Reed, 1971).
This type of soil commonly found in tropical climate area where there is an intense chemical weathering and leaching of soluble minerals (Monroe & Wicander, 2009). Upon exposed to continuous weathering, it leads to changes in chemical compound which resulted in colour changes that indicates the degree of maturity and due to the various degrees of mostly iron, aluminium oxides, manganese, titanium hydration where class I is ferric oxide has colour orange to orange yellow, while class II is red to reddish brown (Posnjak & Merwin, 1919).

According to Tardy (1997), usually the distribution of laterite soil is centred in the tropic zone from latitude around 23.4378° North to 23.4378° South as shown in the Figure 2.2. Whereas Gidigasu (1976) had broader criteria for laterite which is located in tropic and sub tropic area from latitude 35° North and 35° South such as Australia, Africa and America that is crossed by equator as shown in Figure 2.3.

![Figure 2.2: Map of laterite deposit around the world](source: Petrology of laterite and tropical soil, Yves Tardy, 1997).

In Peninsula Malaysia, laterite was distributed around Melaka, Negeri Sembilan, Johor, Kedah, Pahang dan Kelantan as shown in Figure 2.4. Laterite usually found in the hill surface with altitude less than 80 m above the sea level, with height differences between peak and valley around 20 m, and the slope of the hill less than 7° and distance between the hill 200-400 m (Newill & Dowling, 1970).
Traditionally, laterite was used as a building material whether as a mixture in rammed earth, cob or directly cut into brick since laterite possessed good properties which can hardly be found in most of the other stone (Persons, 1970). One of its properties is that laterite does not swell with water hence making it perform well in packing material especially when there is no sandy condition (Maignien, 1996).

The main composition of laterite constitutes of Iron Oxide (Fe₂O₃), Silicon Dioxide, (SiO₂) dan Aluminium Oxide (Al₂O₃) whereas usual compound found in laterite are Carbon Dioxide (CO₂), Calcium Oxide, (CaO), Titanium Dioxide, (TiO₂), Potassium Oxide, (K₂O), Sulfur Trioxide, (SO₃), Sodium Oxide, (Na₂O), and Magnesium Oxide, (MgO) (Bawa, 1957).

Like clay soil application, laterite also used as construction material for its ease to work with in situ. Local soil makes the contructions more sustainable and cost effective and in the same time environmental friendly most notably in tropical country (Kasthurba et al., 2015).

Figure 2.3: Distribution of laterite soil in Peninsula, Malaysia (source: Laterite Soil Engineering: Pedogenesis and Engineering Principles, M. Gidigasu, 1976).
2.3.2 Stabilizers

Stabilizer for CSEB plays an important role in creating bonding between soil-stabilizers mixes. In this study, the term stabilizer is also true for binder in as much as it connects to its role to bind soil and other components of CSEB. One of the main functions of the stabilizing medium is to reduce the swelling properties of the soil through forming a rigid framework with the soil mass, enhancing its strength and durability (Anifowose, 2000).

Portland cement is the most widely used stabilizer for earth stabilization. In term of cement as a binder, cement hold other material to form a cohesive material chemically in a more liquid way like in concrete. In term of cement as stabilizer, it more associated with soil like in brick production and in a drier and bulky way to enhance its properties mechanically by compacting.

Regarding to brick production, the working of stabilizer depends on its plasticity index. Many researches (Guettala et al., 2002; Walker, 1995; Walker & Stace, 1996) found that soil with plasticity index below 15 is suitable for cement stabilization. Typically, cement binder is added between 4 and 10% of the soil dry weight (Mesbah et al., 2004). However, if the content of cement is greater than 10% then it becomes uneconomical to produce CSEB brick. Brick that using less than 5% of cement, it often too friable for easy handling (Walker, 1995).

The most popular stabilizers in the brick making are cement and lime. commercial stabilizers which usually a mixture of chemical binding agents also getting its way in brick production. Several studies have been done in attempt to produce green brick incorporating existing stabilizer and additional substance such as biomass.
2.3.2.1 Cement

Cement is used as a stabilizer for CSEB control samples in this study and its performance will be compared to CSEB with lime as stabilizer. Cement has been well known as the most popular soil stabilizer (Nagaraja et al., 2014) and many researchers have observed the role of cement as stabilizer in CSEB (Guillaud et al., 1995; Kerali, 2001; Venkatarama Reddy & Gupta, 2006; Walker & Stace, 1996).

Cement stabilization increased the unconfined compressive strength of the soil significantly and in general improvement in mechanical properties is higher compared to lime stabilization (Asgari et al., 2015). Soil with moderate plasticity index almost always have higher compressive strength than that of lime stabilizer, however for soil with high plasticity index, lime stabilizer is more superior (Bhattacharja & Bhatt, 2003).

Composition of cement mainly known are three components. First the component that release a lot of heat in the early stage of hydration is Tricalcium aluminate (Ca₃Al₂O₆) or C₃A. The component that responsible of early strength gain is (Ca₃SiO₄) or C₃S. Belite or dicalcium silicate (Ca₂SiO₅) or C₂S is hydrated and hardens slowly and responsible for long term strength gain. These three components will bind the soil in compression with the presence of water.

2.3.2.2 Lime

Not many people aware of the use of lime as binder in concrete preceded the use of pottery (Kingery, 1980). Even though, many believed that concrete was invented by the Romans, archaeological evidence showed that concrete was discovered during Neolithic age (Malinowski & Garfinkel, 1991), long before the Greeks (Koui & Ftikos, 1998) and Phoenicians (Baronio et al., 1997).

The discovery of binding properties of lime was probably discovered when Neolithic people that lived in natural cave carved in limestone, used fire to heat or to cook. It was not far-fetched to find out the binding properties of lime in the way that quicklime easily hydrates in the presence of water and hardens in air (Aitcin, 2008).
The following table is important as consideration in designing the mix proportion of the brick. As soil stabilizer, Ingles and Metcalf (1972) recommended the criteria of lime mixture as shown in Table 2.1 (Ingles & Metcalf, 1972).

Table 2.1: Suggested lime content (%) in soil stabilization by Ingles and Metcalf (1972).

<table>
<thead>
<tr>
<th>Soil Type</th>
<th>Lime Content (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fine crushed rock</td>
<td>Not recommended</td>
</tr>
<tr>
<td>Well graded clay gravels</td>
<td>~ 3 percent</td>
</tr>
<tr>
<td>Sands</td>
<td>Not recommended</td>
</tr>
<tr>
<td>Sandy clay</td>
<td>~ 5 percent</td>
</tr>
<tr>
<td>Silty clay</td>
<td>2 – 4 percent</td>
</tr>
<tr>
<td>Heavy clay</td>
<td>3 – 8 percent</td>
</tr>
<tr>
<td>Very heavy clay</td>
<td>3 – 8 percent</td>
</tr>
<tr>
<td>Organic soils</td>
<td>Not recommended</td>
</tr>
</tbody>
</table>

Through heating process of calcium carbonate (CaCO₃), is released, then in hydration or slaking process, lime absorbs the water. Until the carbonation process then, lime will re-absorb the carbon dioxide (CO₂) again, this known as lime cycle. Because the additional chemical content to make lime more hydraulic, the natural composition of lime will decrease and this will lead to the more hydraulic a lime, the less CO₂ is reabsorbed during set. For example, 50% of CO₂ is reabsorbed by commercial lime product NHL 3.5 during the set, compared to 100% of CO₂ being reabsorbed by pure calcium hydroxide (fat lime putty).

The compressive strength of soil with lime stabilization is more dependent on time rather than dosage, hence it gains strength with time. Bhattacharja and Bhatt (2003) suggest that lime stabilized soil also depend on the pozzolanic reaction for strength gain. The addition of lime to clay is observed can enhance the engineering properties of the soil such as reducing the plasticity, increase the strength and Young’s Modulus (Bell, 1996).
2.4 Properties of CSEB

The benefit of CSEB in view of sustainability is come from its green properties. Owned to the compression process, CSEB has better properties compare to the adobe or mud brick. Followed are the properties of CSEB and its advantages.

2.4.1 Density

Commonly, most researchers found that the density of compressed earth bricks is within the range of 1500 to 2000 kg/m$^3$. Density of the compressed earth brick is consistently related to its compressive strength and compactive force applied during production. The dry density is largely a function of the constituent material’s characteristics, moisture content during pressing and the degree of compactive load applied and even in India compressive strength is controlled by density. Types of compaction applied such as dynamic, static and vibro will also affect the density. The density of brick can be determined through standard procedure such as ASTM C 140 and BS 1924-2 (1990) and others (Bahar et al., 2004; Morel et al., 2005; Oti et al., 2009a; Oti et al., 2009c; Walker, 1999). Brick density above 1700 kg/m$^3$ is fire resistant (Minke, 2006).

2.4.2 Water Absorption and Moisture Content

Water absorption is a function of soil and cement content to absorb and keeping the water level in accordance with the capacity of these materials. Regarding to brick, usually water absorption related with the strength and durability of earth bricks and therefore it is important to determine the rate of water absorption of earth bricks. Water absorption rate decrease with increasing in age of earth bricks and high rate of water absorption of a specimen may cause swelling of stabilized clay fraction and resulting in losing strength with time (Oti et al., 2009c). Water absorption, as well as porosity, also increases with clay content and decreasing cement content (Taallah et al., 2014; Walker & Stace, 1996).

Between cement, lime, cement-lime and cement-resin, combination cement and resin stabilization show the lowest water absorption both in capillary absorption
and total absorption. Freidin & Erell (1995) tried to reduce the water uptake by adding a hydrophobic material, in this case was siloxane-polymethylhydrogen-siloxane and combined with slag + fly ash which is highly absorbent and the result showed that the water uptake with the addition of 0.5% siloxane less than a quarter of the water uptake of fly ash-slag without additive.

Sand content in the mixes apparently can reduce water absorption and weight loss even though does not affect the compressive strength significantly (Guettala et al., 2002). Standard used to determine water absorption is ASTM C 140 for total water absorption, BS EN 771-2 and Australian Standards 2733 for initial rate of absorption (Oti et al., 2009c; Walker, 1999; Walker & Stace, 1996).

Moisture content affects strength development and durability of the material. Moisture content also has a significant influence on the long terms performance of stabilized soil material, especially effect on bonding with mortars at the time of construction. When the brick is dry, water is rapidly sucked out of the mortar preventing good adhesion and proper hydration of the cement and when the brick is very wet the mortars tends to float on the surface without gaining proper adhesion (Walker, 1999).

Types of compaction also affect the optimum water content in the stabilized mixes. Dynamic compaction can reduce the optimum water content from 12% to 10% with the compressive strength increased for about 50%. Bahar et al (2004) stated the optimum water content range between 10 to 13% for static compaction, as for vibro-static compaction slightly increase compressive strength with the same water content for low compressive load. According to Osula (1996) soil-lime mixes required higher optimum moisture content than soil-cement mixes. The Standards that conform to determine water content such as ASTM D 558, Australian Standards 1289, BS 1924-2 (1990), BS EN 1745:2002 and the newest BS EN 1745:2012.

Generally, the acceptable water absorption is between 12% and 20% for clay brick. If using engineering bricks the closer to the 12% the better the result will be but when the water absorption is too low, i.e. below 12%, it may be difficult to obtain a proper bond between the mortar and the bricks (Vuuren & Cermalab, 2013).

In addition, correspond to moisture content, as earth masonry, CSEB will absorb more moisture compared with other building materials as shown in the Figure 2.5. According to Morton (2008) earth brick absorb more moisture than other
construction materials as shown in Figure 2.4. Also CSEB has the ability to regulate relative humidity of indoor air in the building which is the key attribute of earth masonry. The ability of CSEB to absorb and desorb atmospheric moisture comes from its clay mineral structure.

![Figure 2.4: Air moisture absorbed from several materials](source: Morton, 2008).

### 2.4.3 Strength

Compressive strength is the most universally accepted value for determining the quality of bricks. Nevertheless, it intensely related with the soil types and stabilizer content. Typically, determination of compressive strength in wet condition will give the weakest strength value. Reduction in compressive strength under saturation condition can be attributed to the development of pore water pressures and the liquefaction of unstabilized clay minerals in the brick matrix. Factors affecting the CSEB brick strength are cement-content, types of soil (plasticity index), compaction pressure and types of compaction.

Optimum cement content for the stabilization is in the range of 5% to 10% where addition above 10% will affect the strength of the bricks in negative way. Plasticity index of the clay soil is usually in the range of 15 to 25. The best earth soils for stabilization are those with low plasticity index. But for plasticity index >20, it is not suitable with manual compaction (Walker, 1995). Anifowose
(2000) found that irons present in the soil are responsible for low compressive strength in the soil stabilization process. The strength of the CSEB can be increased by adding natural fibres where it can improve the ductility in tension. The improvement is by retarding the tensile crack propagation after initial formation and also the shrinkage cracking (Mesbah et al., 2004).

Since there is no standard testing for CSEB at the moment, most researchers determined the compressive strength using the testing method used for fired clay brick and concrete masonry block such as ASTM 1984, BS 6073-1:1981, BSI 1985, BS EN 772-1, BS 1924-2:1990, Standard Australia 1997, Australian Standard 2733 (Oti et al., 2009a; Oti et al., 2009c; Walker, 1995, 2004). The unconfined compressive test needs expensive equipment and must be carried out in the laboratory, hence some researchers suggest using indirect compressive test (i.e. flexural test/modulus of rupture/three-point bending test). These indirect test provide simple, inexpensive and fast assessment of in-situ bending strength of the brick (Morel & Pkla, 2002; Morel et al., 2005). Walker (1995, 2004) suggested to use factors that modulus of rupture is equivalent with one-sixth of its compressive strength and in his latest experiment suggested that unconfined compressive strength is about five times of the bending strength.

Compacting procedure also affect considerably on the compressive strength of the CSEB brick. Guettala et al (2002) concluded that by increasing the compacting stress from 5 to 20 MPa, it will improve the compressive strength up to 70%. His conclusion was strengthened by Bahar et al (2004) observed that by using dynamic compaction energy dry compressive strength increases by more than 50% but for vibro-static compaction increases slightly for about 5%.

Because earth structures should not be under tension therefore tensile strength for earth building materials has no relevance (Minke, 2000).

Brick strength and brick characteristic flexural bond strength are the factors that limiting the bond strength between bricks and mortars in wall panels made from CSEB (Walker, 1999). Hence, types of bricks such as solid, interlocking or hollow and type of bond like English, Flemish or Rat trap bond also play an important role in flexural strength of the panels (Jayasinghe & Mallawaarachchi, 2009).
2.4.4 Durability

The basic principle of stabilization in CSEB is how to attained high mechanical strength while, at the same time averted moisture intake when exposed to wet condition. From several experiments, brick’s durability associated with the stabilizer content, clay content, compacting stress and weather condition. Primarily, durable stabilized soil material building can be achieved as long as they are not saturated. The problems arise when the materials are subjected to the long-term saturation and exposed to various climatic conditions. Also, it is observed that the present of unstabilized material was likely to be particularly detrimental to the durability.

Heathcote (1995) observed that rain drop can discharge kinetic energy that impacted the brick and causing material falling from the surface of wall panels. He stated that wet/oven dry ratio of 33% may be a suitable criterion for evaluating the durability of cement stabilized earth specimen.

In the tropical climate, soluble salt most commonly sodium sulphate and sodium chloride can cause salt attack in brick. Salt attack caused cristallization of salt in the pore structure and in turn will create a pressure that caused rupture in the material (Bakar et al., 2011). Soluble salt transported to the brick through the seepage from ground water or near the sea through the air, that can lead to rising damp and salt attack which in turn can destroy the brick.

As observed by Oti et al (2009b) combination of bricks that made of clay, cement, lime and Ground Granulated Blast Furnace (GGBS) are subjected up to 100 cycles 24 hours repeated of freezing and thawing showed satisfaction result where only having maximum 1.9% weight loss at the end of the 100th cycles. This examination is done after the test showed no damaged occur of any type.

The measurement of durability according to the standards such as ASTM normalization (ASTAM 1993), ASTM D 599-57 (resistance to water erosion), ASTM 560 and DDCENT/TS 772-22 (freeze-thaw test), wire brush test, Australian Standards 2002, Doat, et al. (1979) using water spray test and Yarin, et al (1995) using water drip test, are very severe compared to the natural condition. Nevertheless, in general, clay material still have potential to damage from rising damp, freeze/thaw cycles and surface erosion caused by wind-driven rain as clay
mineral tend to disrupt the cement action (Guettala et al., 2002; Oti et al., 2009a; Oti et al., 2009c; Walker, 1995, 1999, 2004; Walker & Stace, 1996).

### 2.4.5 Thermal Value

In the growing concern of energy conscious and ecological awareness, thermal comfort in building materials is an important aspect that attracts great attention since building regulations nowadays stressing more on the thermal performance of the buildings compare to the past.

Heat transfer of a building is characterized by its thermal conductivity. As the building material, earth brick is good thermal conductivity. Oti (2009b) observed that thermal conductivity is a function of the material density and moisture content. Thus design value for thermal conductivity can be determined through experimental and theoretical method. Compressed stabilized earth bricks showed better thermal conductivity value compare to the fired clay bricks.

- Lime-GGBS based: $0.2545 \pm 0.0350 \text{ Wm}^{-1}\text{K}^{-1}$
- Cement-GGBS based: $0.2612 \pm 0.0350 \text{ Wm}^{-1}\text{K}^{-1}$
- Fired clay bricks: $0.4007 \pm 0.0350 \text{ Wm}^{-1}\text{K}^{-1}$

The lower the thermal conductivity value of the brick is the better considering it is directly proportional with the materials thermal mass value. Thermal mass value is the ability of materials to absorb and gives off heat deliberately after long period of time. Therefore, if the materials possessed low thermal conductivity which caused in low thermal mass, then in turn it will result in low energy consumption that is good in term of sustainable and green materials.

Thermal conductivity can be decreased somewhat low by addition of cement and sand content (Bahar et al., 2004). Firing process of fired brick caused it has high thermal conductivity compared to earth brick since the firing process change the clay particle to form glassy substance and having mineral breakdown and forming crystalline phase.

The following standards such as BS EN 1745 (thermal conductivity and thermal resistance), ASTM C 518-91 and ASTM C 1132-89 (thermal value) can be
used to determine the thermal value of compressed stabilized earth bricks (Oti et al., 2009b).

Effect of this thermal conductivity is the indoor temperature. Earth house temperature will varied by 5°C while concrete house 16°C and at 4 pm the concrete house 5°C higher than outside temperature while earth house 5°C lower than outside (Fathy, 1986). The experiment was done in hot arid climate area with two identical building one was built with 50-cm-thick earth walls when the other of 10-cm-thick pre-cast concrete.

### 2.4.6 Carbon Emission and Embodied Energy

A striking contrast between CSEB and conventional fired bricks is the energy consumed during the production process and carbon emission. CSEB brick creates 22 kg CO₂/tonne compared to that of concrete blocks (143 kg CO₂/tonne), common fired clay bricks (200 kg CO₂/tonne) and aerated concrete blocks (280 – 375 kg CO₂/tonne) during production as illustrated in Figure 2.5 (Morton, 2008). In average, cement stabilized earth bricks consumed less than 10% of the input energy as used to manufacture similar fired clay and concrete masonry unit (Walker, 1995).

![Figure 2.5: Values of ‘factory gate’ embodied carbon for masonry materials (source: Morton, 2008).](image)

The embodied energy is the total amount of energy used in bringing the material to its present state and location, or in other words as the energy that could have been save, had the product never been manufactured. Straightforward method to determine the embodied energy of the masonry may not be available now, but indirect method can be obtained from Morton (2008) where embodied energy of 146
REFERENCES


economical evaluation of a rice husk ash (RHA) based sand-cement block for
reducing solar conduction heat gain to a building. *Construction and Building

Liou, T.-H. (2003). Preparation and characterization of nano-structured silica from

architectural use and manipulation of brick from mediaeval times to the end

Activity of Natural Products by Conductivity Measurement. *Cement and
Concrete Research, 19*(1), 63-68.

activity of natural products by conductivity measurement. *Cement and
Concrete Research, 19*(1), 63-68. doi:http://dx.doi.org/10.1016/0008-
8846(89)90066-5

alternative material in producing high strength concrete*. Paper presented at
the International Conference on Engineering Materials, Ottawa, Canada.

UNESCO.


activation with calcium hydroxide. *Construction and Building Materials,
10*(3), 179-184. doi:http://dx.doi.org/10.1016/0950-0618(95)00089-5

activation with calcium hydroxide. *Construction and Building Material,
10*(3), 179-184.


