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Abstract

In the operation of coal-fired power plants in the Philippines, the pulverized coal which is
used as a source of energy and depending on its coal burning furnace, tends to produce
approximately 80% of Coal Fly Ash and 20% of Coal Bottom Ash. Researches and
studies have shown that Coal Bottom Ash can be used as a road base subbase
aggregate, structural fill material (ASTM E1861-97), and as fine aggregates in asphalt
paving and flowable fill. From recent studies done by Gallardo et. al. in De La Salle
University- Manila, Coal Bottom Ash was used as partial substitute to sand for building
materials like Concrete Hollow Blocks complying to the Philippine National Standards.
The casting and testing of 429 specimens of four-inch-thick hollow blocks and variable
mix proportions were considered in the research. However, with the data produced,
design of simplified mix proportions was not yet done and still to be modeled. Using
neural network self-organizing map to classify organized data sets, a simplified approach
to mix proportions was made to meet the mechanical properties needed to comply with
the Philippine National Standards in Concrete Hollow Blocks.

Keywords: Artificial Neural Network, Concrete Hollow Blocks, Coal Bottom Ash

I. Coal- Fired Power Plants Worldwide

The world comes across significant environmental challenges with the vast operation of coal fired
power plants. The major problem faced by this industry is how the coal burning process pollutes the
earth. Potentially hazardous wastes produced from this process lead to the deterioration of the
physical environment and contribute even more to global warming. The burning of coal produces large
amounts of fly ash, bottom ash, boiler slag and flue gas desulfurization sludge are collectively referred
to as coal combustion wastes. Today coal combustion wastes is the second largest industrial waste
stream in America next to mining waste [1]. Various environmental problems to soils and waters often
results from the disposal of coal combustion wastes.

In 2005, China was ranked as the top producer of coal which covers one-third world share followed by
USA and India according to British Geological Survey. Despite the China’s stable economic growth
brought by its coal fired power plant industry, the country suffers greatly from health problems and
physical environment damages due to the rapid exploitation and high dependency of coal productivity.

Worldwide, coal-fired power generation presently accounts for roughly 38% of total electricity
production. In some countries such as China and India it accounts for as much as 50%. [2].
Considerable increases in coal-fired generation capacity are rapidly arising in mostly developing
countries. The production and development of the coal fired power plant industry have rather given
developing countries’ stability in their economic growth.
The purpose of a coal-fired power plant is primarily to produce electricity and heat through combustion. The coal is pulverized and burned in a furnace with a boiler. This process generates heat that converts the boiler water to steam. The steam is then used to spin turbines which create electricity. Figure 1 shows the generation and use of coal combustion product in the USA.

![Figure 1. Coal Combustion Product Generation and Use in USA](image)

Combustion wastes produced from these plants are often used in construction and highway applications. Fly ash can be used as a substitute for Portland cement in concrete and grout, as fill material in embankments, as aggregates for highway subgrades and road base, and as flowable fill. Bottom ash can be used as aggregate in concrete and in cold mixed asphalt, and as a structural fill for embankments and cement stabilized bases for highway construction. Shown in Figure 2 is the utilization of combustion wastes in USA.

<table>
<thead>
<tr>
<th>Uses of CCP’s</th>
<th>Fly Ash</th>
<th>Bottom Ash</th>
<th>Boiler Slag</th>
<th>FGD Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concrete/concrete products/grout</td>
<td>12,265,169</td>
<td>298,181</td>
<td>15,907</td>
<td>99,077</td>
</tr>
<tr>
<td>Structural fills/embankments</td>
<td>5,496,948</td>
<td>2,443,206</td>
<td>11,074</td>
<td>236,241</td>
</tr>
<tr>
<td>Cement/raw feed for cement clinker</td>
<td>3,024,930</td>
<td>490,765</td>
<td>15,766</td>
<td>422,512</td>
</tr>
<tr>
<td>Road base/sub-base/pavement</td>
<td>493,467</td>
<td>1,138,101</td>
<td>29,800</td>
<td>0</td>
</tr>
<tr>
<td>Snow and ice control</td>
<td>1,928</td>
<td>603,556</td>
<td>102,700</td>
<td>0</td>
</tr>
<tr>
<td>Aggregate</td>
<td>137,171</td>
<td>512,769</td>
<td>31,600</td>
<td>6,299</td>
</tr>
<tr>
<td>Flowable Fill</td>
<td>136,616</td>
<td>20,327</td>
<td>0</td>
<td>9,164</td>
</tr>
<tr>
<td>Mineral filler in asphalt</td>
<td>52,608</td>
<td>0</td>
<td>31,402</td>
<td>0</td>
</tr>
<tr>
<td>Well bore</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>7,780,906</td>
</tr>
<tr>
<td>Waste stabilization/solidification</td>
<td>3,919,808</td>
<td>30,508</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Mining applications**</td>
<td>683,925</td>
<td>1,184,927</td>
<td>59,800</td>
<td>390,331</td>
</tr>
<tr>
<td>Blasting grit/roofing granules</td>
<td>0</td>
<td>42,604</td>
<td>1,455,140</td>
<td>0</td>
</tr>
<tr>
<td>Soil modification/stabilization</td>
<td>515,552</td>
<td>67,998</td>
<td>0</td>
<td>818</td>
</tr>
<tr>
<td>Miscellaneous/other</td>
<td>406,290</td>
<td>1,331,331</td>
<td>2,815</td>
<td>34,013</td>
</tr>
<tr>
<td>Total</td>
<td>27,138,524</td>
<td>8,247,273</td>
<td>1,758,004</td>
<td>8,980,981</td>
</tr>
</tbody>
</table>

![Figure 2. Details of Coal Combustion Product Use in USA](image)

*Flue gas desulfurization materials include FGD gypsum, FGD material wet scrubbers, FGD material dry scrubbers and FGD other.

**EPA and the National Academy of Sciences are evaluating the use of coal combustion products as minefill and will address this issue separately.
II. Coal-Fired Power Plants in the Philippines

Five operational coal-fired power plants are operated in the Philippines today. These are the 300MW plant in Brgy. San Rafael, Calaca, Batangas, the 600MW plant in Brgy. Bani, Masinloc, Zambales; the 433MW plant in Brgy. Cagsiay I, Mauban, Quezon and the 700MW plant in Brgy. Polo-Ibaba, Pagbilao, Quezon; and the 1,200MW plant in Brgy. Pangascasan, Sual, Pangasinan. The main problem that arises from the use of the plant is disposal of coal combustion products. Shown in Figure 3 are the percentages of the sources of electricity. It can be observed that in the Philippines, major contributor of electricity source is the coal-fired power plant.

III. Calaca, Batangas Coal-Fired Thermal Power Plant (BCFTPP), Philippines

The researchers collaborated with one of the coal-fired power plant in the Philippines to provide solution to the rising environmental problems. The power plant was Calaca coal-fired thermal power plant. It is a 600 megawatt(MW) conventional, pulverized coal fired power plant.
plant. It consists of two 300 MW coal-fired units commissioned in 1984 and 1995. The plant occupies an area of 168 hectares in the municipality of Calaca, Batangas about 115 km south of Manila. Shown in Figure 5 and 6 is the production of Coal Bottom Ash (CBA) and stockpile of Coal Bottom Ash, respectively. [3]

<table>
<thead>
<tr>
<th>Coal Consumption</th>
<th>BCFTPP 1</th>
<th>BCFTPP 2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>139.43 t/hr</td>
<td>184.54 t/hr</td>
</tr>
<tr>
<td>% Ash content</td>
<td>4.56%</td>
<td>12.14%</td>
</tr>
<tr>
<td>Total ash content</td>
<td>3.815 t/hr</td>
<td>6.771 t/hr</td>
</tr>
<tr>
<td>25% of ash content is CBA</td>
<td>0.95 t/hr</td>
<td>1.69 t/hr</td>
</tr>
<tr>
<td>Total CBA produced per day</td>
<td>63.36 tons</td>
<td>134.40 tons</td>
</tr>
</tbody>
</table>

Figure 5. Coal Bottom Ash Production in Calaca, Batangas Coal-Fired Thermal Power Plant (BCFTPP), Philippines

Figure 6. Stockpile of CBA in Calaca, Batangas Coal-Fired Thermal Power Plant (BCFTPP), Philippines

Experimental procedures and testing of Concrete Hollow Blocks (CHB) were made to cast and produce the most common type of Concrete Masonry Units (CMU) in the Philippines. The research produced 429 CHB specimens.

IV. Concrete Hollow Blocks

Concrete Hollow Blocks are classified into four common ingredients: cement, fine aggregate, coarse aggregate, and water. The compressive strength of which is determined by the following factors: water-cement ratio, fine-coarse aggregate ratio, cement-aggregate ratio of the given mix proportion. Standard curing time for 28 days is required for each manufactured block. Philippine National Standard (PNS) categorizes the types of block as listed in Table 1. Type I are classified as load-bearing hollow blocks while Type II as non load-bearing hollow blocks. Shown in Figure 7 are some of the CHBs produced in the study.
Table 1. PNS Strength Requirement for Concrete Hollow Blocks [4]

<table>
<thead>
<tr>
<th>Compresive Strength</th>
<th>Type I (Class A)</th>
<th>Type I (Class B)</th>
<th>Type II</th>
</tr>
</thead>
<tbody>
<tr>
<td>Individual Test</td>
<td>5.6 Mpa</td>
<td>4.2 Mpa</td>
<td>2.1 Mpa</td>
</tr>
</tbody>
</table>

Figure 7. Four-Inch Thick CHB in Science, Technology and Research Center, De La Salle University- Manila

IV. Research Experiments

The procedure that was followed the experiment was taken from American Concrete Institute (ACI 211.3R-97, Guide for Selecting Proportions for No-Slump Concrete) where it stated the suggested blending of aggregates used for making load bearing concrete hollow blocks shall have a fineness modulus close to or equal to 3.7, within the practical limits for load bearing concrete hollow blocks. Practical limits is a range of fineness modulus where the combination of aggregates would be appropriate for a specific application. [5]

Experimental study utilizing coal bottom ash as a partial substitute to sand in the production of concrete hollow blocks (CHBs) was conducted. The testing of 429 pieces of four-inch-thick hollow blocks were considered in the study with variable mix proportions such as: water-cement ratio(w/c), cement-aggregate ratio(c/a), and coal bottom ash percent substitution(CBA). Shown in Figure 8 are the parameters that were varied to come up with database of results. The overall dimension of the CHB is 4 inches thick, 200mm height and 400mm length.

Figure 8. Variation of Design Mix in the Study

The cement-aggregate ratio (c/a) refers to the ratio of cement and total aggregate ratio, while the total aggregate content comprises of two parts: 30% fine aggregates and 70% coarse aggregates. The CBA in this research was used to substitute the amount of fine aggregates in percentage illustrated in Figure 8.
Compressive Testing were made for each specimens in the Science, Technology and Research Center, De La Salle University- Manila. Shown in Figure 9 is the set-up of the laboratory.

Figure 9. Structural Testing Laboratory at Science, Technology and Research Center, De La Salle University- Manila

V. Self-Organizing Map (SOM)

After the production and experiments on the produced CHB specimens, screening of data were made to come up with significant amount of data that will suffice in making design mix that complied with Philippine National Standards (PNS) [6]. Out of the 429 specimens produced, only 66 specimens were considered in the Self-Organizing Map to classify sets and arrive at a design mix to comply with PNS.

What is self-organizing map? It is an unsupervised neural network learning algorithm that classifies sets of data into organized groups. From the 66 data sets, SOM was used having water-cement ratio (w/c), Coal Bottom Ash Content (CBA), and Cement-Total Aggregate Ratio (c/a) as the data sets to be classified into four organized groups.

VI. Results and Discussion

From the SOM model derived to classify the parameters water-cement ratio (w/c), Coal Bottom Ash Content (CBA), and Cement-Total Aggregate Ratio (c/a) into four organized groups, further analysis was incorporated to the compressive strength at the 28th day age (f’c).

In the Philippines, there are three classes under the PNS shown in table 1. From the four organized groups A, B, C, and D, the following observations were made:

1.) Groups A and B refers to strength having TypeI(ClassA) with individual compressive strength of 5.6MPa under PNS
2.) Group A consisted only with water-cement ratio of 0.40 and with more cement content
3.) Group B consisted with both water-cement ratio of 0.40 and 0.50, and with lesser cement content
4.) Group C refers to strength having TypeI(Class B) with individual compressive strength of 4.2 MPa under PNS
5.) Group D refers to strength having TypeII with individual compressive strength of 2.1MPa under PNS
Careful analysis on the sub-data sets from SOM were made to satisfy the required strength and at the same time to be economical by reducing the amount of cement needed in the design mix. Table 2 and Table 3 are the proposed mix design from SOM groups that complied with PNS with reference to its mean compressive strength.

### Table 2. SOM sub-sets having water- cement ratio = 0.40

<table>
<thead>
<tr>
<th>Group</th>
<th>Cement-Total Aggregate Ratio(c/a)</th>
<th>CBA Content</th>
<th>Minimum ( f'c ) (MPa)</th>
<th>Mean ( f'c ) (MPa)</th>
<th>Maximum ( f'c ) (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>1:5</td>
<td>20%</td>
<td>5.65</td>
<td>5.65</td>
<td>5.65</td>
</tr>
<tr>
<td>B</td>
<td>1:8</td>
<td>20%</td>
<td>5.47</td>
<td>5.75</td>
<td>6.28</td>
</tr>
<tr>
<td>C</td>
<td>1:10</td>
<td>20%</td>
<td>4.47</td>
<td>4.74</td>
<td>5.01</td>
</tr>
<tr>
<td>D</td>
<td>1:15</td>
<td>40%</td>
<td>2.06</td>
<td>2.79</td>
<td>3.52</td>
</tr>
</tbody>
</table>

### Table 3. SOM sub-sets having water- cement ratio = 0.50

<table>
<thead>
<tr>
<th>Group</th>
<th>Cement-Total Aggregate Ratio(c/a)</th>
<th>CBA Content</th>
<th>Minimum ( f'c ) (MPa)</th>
<th>Mean ( f'c ) (MPa)</th>
<th>Maximum ( f'c ) (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>B</td>
<td>1:5</td>
<td>40%</td>
<td>5.48</td>
<td>5.62</td>
<td>5.76</td>
</tr>
<tr>
<td>C</td>
<td>1:10</td>
<td>40%</td>
<td>4.44</td>
<td>4.44</td>
<td>4.44</td>
</tr>
<tr>
<td>D</td>
<td>1:12</td>
<td>40%</td>
<td>3.52</td>
<td>3.59</td>
<td>3.67</td>
</tr>
</tbody>
</table>

The authors recommend the following mix proportions as highlighted in Table 2 and Table 3. Note that the total aggregate is comprised of two parts: 30% fine aggregate and 70% coarse aggregate. Shown in Table 4 is the recommendation. The factors that affected the recommended mix proportions were:

1.) Less cement content means more economical
2.) More CBA utilized means more environment friendly

### Table 4. Recommended Mix Design

<table>
<thead>
<tr>
<th>PNS Type</th>
<th>Water-Cement Ratio</th>
<th>Cement: Fine Aggregate: Coarse Aggregate Ratio</th>
<th>Maximum CBA substitution for fine aggregates</th>
<th>PNS required ( f'c )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type I (Class A)</td>
<td>0.50</td>
<td>1:1.5 : 3.5</td>
<td>40%</td>
<td>5.6MPa</td>
</tr>
<tr>
<td>Type I (Class B)</td>
<td>0.50</td>
<td>1:3 : 7</td>
<td>40%</td>
<td>4.2MPa</td>
</tr>
<tr>
<td>Type II</td>
<td>0.40</td>
<td>1:4.5 : 10.5</td>
<td>40%</td>
<td>2.1MPa</td>
</tr>
</tbody>
</table>

### VII. Conclusions

The source of electricity in the Philippines is mostly from coal-fired power plants. In the future, demand on electricity in the Philippines will increase, solutions in environmental problems should be addressed. In this research, the focus was to utilize coal bottom ash that is stockpiled near the Calaca, Batangas Coal-Fired Thermal Power Plant. In order for it to be utilized properly, studies and experiments were made to come up with a mix proportion using coal bottom ash as a substitute to fine aggregates. Tools such as neural network self-organizing map was used to classify organized data sets to come up with a mix proportions to comply with the Philippine National Standards in Concrete Hollow Blocks.
REFERENCES:


