"APPLICATION OF COAL COMBUSTION BY-PRODUCTS IN MASONRY PRODUCTION"

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Application of Coal Combustion By-Products in Masonry Production

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ABSTRACT

A research program at the Center for By-Products Utilization, UW-Milwaukee, is being conducted to develop new low-cost construction materials primarily using coal combustion by-products. This paper presents research performed to develop mixture proportioning information for room cured bricks utilizing Class C fly ash. Methods of preparing the mix, molding and curing, as well as compressive strengths and unit weights of specimens have been described in this paper. The research shows that low-cost construction materials can be reliably developed using coal combustion by-products.

INTRODUCTION

Despite significant progress during the last 10 years toward the increased use of fly ash in the construction industry, only very small amounts of fly ash and bottom ash are used in manufacture of low-cost construction materials, such as bricks. Brick manufacture is one area where there is potential to use large quantities of fly ash. The idea of using fly ash and bottom ash as the raw materials for bricks is not new. However, literature indicates that most research was aimed at manufacture of fired or steam cured fly ash
bricks [1-21] in the United States. Only a few papers described research on unfired or room cured products [22-24]. Compared with fired or steam cured methods, room curing has the advantage of flexibility in manufacturing, and savings in capital costs as well as manufacturing costs. Thus cost efficiency are achieved due to low-cost raw materials and because special curing chambers are not required and energy is not used in manufacturing.

In 1989 the Center for By-Products Utilization at the University of Wisconsin-Milwaukee under sponsorship from the Electric Power Research Institute undertook a research project. The purpose of this research project was to manufacture bricks which meet ASTM specifications using fly ash as the primary binder material and bottom ash as coarse aggregates. The main objective of this research project was to develop mixture proportioning information for room cured bricks, containing high fly ash content, high compressive strength and low unit weight. This paper reports the initial findings about strength development and unit weight.

MATERIALS

The fly ash used in this project was produced by the Dairyland Power Cooperative at their Alma Plant. It meets the ASTM C-618 Class C designation, see Table 1.
Other materials used in this project were Type I Cement, hydrated lime, locally available natural sand and 3/8 in. size pea gravel as coarse aggregates. Normal water reducing retarder was used to improve the workability and the setting time.

PRELIMINARY MIX PROPORTIONATING AND SPECIMEN PREPARATION

Pilot tests were performed to determine the best method of brick mixture proportion in an economic manner. Six levels of fly ash, ranging from 20% to 70% were investigated together with 0, 5%, 10%, and 20% lime, or 0, 5%, 10%, and 15% cement separately. These percentages are based upon total weight of the mix. For each mixture, workability was determined using the Flow Table Test Method (ASTM C-230). Flow was maintained in the range of 9 in. to 10 in. (22 cm to 25 cm). Flow range were judiciously chosen for each mixture in consideration of adequate molding needs.

In order to simplify the molding procedure and to reduce manufacturing costs, machine pressing was not used. Specimens were made by making semi-dry and semi-slurry of the mixture, and casting it directly into the mold, hand compacting (ASTM C-109) and a vibration table (ASTM C-192) were used to compare results. After curing for one day in the fogroom (temperature 23±3°C), specimens were then removed from molds and placed back in the fogroom until the time of test. From each mixture, nine 2 in. cubes were prepared for tests.
of compressive strength and unit weight. Three cubes were tested for strength at 3, 7, and 28 days test age. Compressive strength tests were performed in accordance with the ASTM Standard Method (C-192).

RESULTS AND DISCUSSION

Fig. 1 shows 28-day compressive strength vs. fly ash content at 0% cement and 0% lime. Fig. 2 shows 28-day compressive strength vs. fly ash content at 5% cement and 0% lime.

Fig. 1 and Fig. 2 also show results of compressive strength from hand compacting and vibration compacting. Two groups of mixture were selected. Fig. 1 shows fly ash as the binder material. Fig. 2 shows data for cement plus fly ash as the binder material. It is clear that the vibration method resulted in higher compressive strength than hand compacting. Since the vibration results in improved density of the mixture, it leads to higher compressive strength.

Figs. 3, 4, and 5 show the compressive developments with different binder contents. Fig. 3 shows that the mixture contain only fly ash as the binder material. Fig. 4 and 5 show that the mixtures contain fly ash together with 5% cement or 5% lime, respectively. The results indicate that generally the compressive strength increased with the fly ash content increase. This fly ash has a higher pozzolanic
activity with cement at 28-days (Table 1). From Fig. 3 (the mixture contain only fly ash as the binder material and fig. 4 (the mixture contain fly ash together with 5% cement), the peak compressive strengths were achieved at all ages for mixtures containing between 50% to 60% fly ash. Fig. 5 shows that the compressive strength increased with fly ash content increase, no peak compressive strength occurred up to 70% fly ash content mixtures tested. From Fig. 3, at the level of 20% to 70% fly ash content, 28-days compressive strength range from 2500 psi to 6500 psi (0% cement and 0% lime in the mix). From Fig. 4, for the same fly ash content level, 28-days compressive strength range from 4000 psi to 7000 psi (5% cement and 0% lime in the mix). From Fig. 5, for the same fly ash content level, 28-days compressive strength range from 1500 psi to 3000 psi (5% lime and 0% cement in the mix). Comparing Fig. 3, Fig 4 and Fig. 5 the, results further show that using cement plus fly ash as binder material had a higher strength, but using lime plus fly ash as binder material had lower strength with compared to mixture containing fly ash only.

Fig. 6 shows compressive strength vs. fly ash content at four cement content levels (0% lime). Fig. 7 shows compressive strength vs. fly ash content at four lime content levels (0% cement). Fig. 8 shows 28-day compressive strength vs. cement content (0% lime). Fig. 9 shows 28 days compressive strength vs lime content (0% cement).
Fig. 6 shows that as the cement content increases, compressive strength also increases. Fig. 7 shows that as the lime content increases, the compressive strength decreases. These results are more significant as indicated in Fig. 8 and 9. For the same fly ash content level, compressive strength increased with the cement content increase, but it decreased with the lime content increase.

From table 2 it can be seen that as the lime content increases, in order to maintain the same workability as no lime mixture, more water was required. This leads to higher water to lime plus fly ash ratio, and lower compressive strength. Also as the lime content increased, the higher initial hydration activity caused fast setting, leading to lower a weaker crystalline structure and lower strength.

Fig. 10 shows the compressive strength vs. aggregates content at different fly ash percentages. Test results indicate that as the aggregate content increases, the compressive strength also increases.

Unit weight test results are reported in Fig. 11 and 12. In general, test results indicate that unit weight slightly increased with the increase in aggregates. Comparing Fig. 11 and Fig. 12, the unit weight for the mixture contain lime and fly ash as binder materials (Fig. 12) is slightly lower than that using cement and fly ash as binder materials (Fig. 11).
CONCLUSIONS

Based on the testing work carried out, the following conclusions can be derived from the initial research:

(1) Sufficient strength develops (greater than 2000 psi) after the specimens (containing cement plus fly ash) were cured at fogroom for 28 days and no firing or steam curing was required.

(2) The vibration compacting method was better for obtaining higher compressive strengths.

(3) As the amount of fly ash increases, the compressive strength increases. For the mixture containing cement together with fly ash as binder materials, the peak compressive strength were achieved at the 50% to 60% fly ash level.

(4) When cement or lime were used together with fly ash as binder materials, cement content had positive effect and lime content had negative effect on the compressive strength.

(5) Aggregate content increase can significantly raise strength properties. In general, the more aggregates in the mixture,
the higher the compressive strength.

(6) Cement, lime and fly ash contents did not have very significant influence on the unit weight. The unit weight increased with the aggregate content increase.

(7) Based on the combined analysis of results, the suggested composition of fly ash bricks is fly ash 50%, cement 5% and aggregate 45%.
REFERENCES


Table 1: Chemical and Physical Properties of Fly Ash

<table>
<thead>
<tr>
<th>Chemical Composition</th>
<th>Test Results</th>
<th>ASTM C-618 Requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silicon Oxide (SiO₂), %</td>
<td>32.2</td>
<td>-----</td>
</tr>
<tr>
<td>Aluminum Oxide (Al₂O₃), %</td>
<td>18.4</td>
<td>-----</td>
</tr>
<tr>
<td>Iron Oxide (Fe₂O₃), %</td>
<td>5.8</td>
<td>-----</td>
</tr>
<tr>
<td>Total (SiO₂ + Al₂O₃ + Fe₂O₃), %</td>
<td>56.4</td>
<td>50.0 Min.</td>
</tr>
<tr>
<td>Calcium Oxide (CaO), %</td>
<td>31.7</td>
<td>-----</td>
</tr>
<tr>
<td>Loss On Ignition, %</td>
<td>0.9</td>
<td>6.0 Max.</td>
</tr>
</tbody>
</table>

Physical Test:

<table>
<thead>
<tr>
<th>Physical Test</th>
<th>Test Results</th>
<th>ASTM C-618 Requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fineness (% Retained on #325 wet sieve)</td>
<td>33.8</td>
<td>34.0 Max.</td>
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<tr>
<td>Pozzolanic Activity with Cement 28-days, psi</td>
<td>102</td>
<td>75.0</td>
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<tr>
<td>Water requirement (% of the control)</td>
<td>94.4</td>
<td>105</td>
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<tr>
<td>Specific Gravity</td>
<td>2.66</td>
<td>-----</td>
</tr>
</tbody>
</table>

Table 2 Mix proportions for specimens containing lime plus fly ash as binder material.

<table>
<thead>
<tr>
<th>MATERIAL</th>
<th>MIXTURE</th>
<th>WEIGHT</th>
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</thead>
<tbody>
<tr>
<td>Lime (9)</td>
<td>0</td>
<td>115</td>
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<tr>
<td>Fly Ash (9)</td>
<td>1400</td>
<td>1400</td>
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<tr>
<td>Aggregates (8)</td>
<td>2100</td>
<td>1925</td>
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<tr>
<td>Water (ml)</td>
<td>315</td>
<td>385</td>
</tr>
<tr>
<td>Water to lime plus fly ash ratio</td>
<td>0.23</td>
<td>0.31</td>
</tr>
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</table>