

Evaluation of Processed Bottom Ash for Use as Lightweight Aggregate in the Production of Concrete Masonry Units

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ABSTRACT

Bottom ash generated at the Rockport Power Plant in Rockport, IN as well as two other ashes, were evaluated as a candidate aggregates for the production of lightweight Concrete Masonry Units (CMU's). The objective was to assess the suitability of the aggregate for producing CMU's with a unit weight of less than 30 lbs. while achieving a minimum compressive strength of 1000 psi.

Several gradations were tested using a modified Proctor Density test in order to maximize the packing of the aggregate, thereby reducing the cement requirements necessary to achieve adequate compressive strength. Test cylinders were then produced with a pneumatic press using the selected gradation and varying the cement/aggregate ratio. Compressive strengths of the cylinders were determined after 3, 7, 14 and 28 days of curing in humidified conditions to improve the understanding of strength development. Varying proportions of fly ash (Class C and Class F) were then substituted for the aggregate and it was determined that Class C fly ash provided significant early strength development compared to Class F fly ash. An additional round of testing was conducted using the optimized gradation and fly ash substitution to further reduce the cement requirements and maintain adequate strength.

The final phase of the evaluation was to produce standard 8"x 8"x16" blocks using a laboratory-scale block machine to compare the compressive strength of the blocks with the cylinder specimens.

INTRODUCTION

Most CMU's are produced with a combination of sand and locally available coarse aggregate such as limestone. Standard hollow core units (i.e. 8"x8"x16") have a unit weight in the range of 34 to 40 pounds¹. Lightweight CMU's of similar dimension are also produced for a variety of specialty construction purposes that require the lower weight. Lightweight CMU's are commonly produced from manufactured aggregates such as of expanded shales or clays. While the thermal treatment required for producing these materials results in a consistent, high quality product, it is not surprising that the cost of manufactured aggregate is much higher than that of natural aggregates, a consideration that frequently limits its use.

Coal combustion bottom ash can be similar in many ways to manufactured aggregate. The high temperatures during combustion in combination with turbulent air flow results in a porous bottom ash with bulk densities of 45 to 75 lb/ft³, similar to manufactured aggregate. Adequate processing of the bottom ash can potentially provide the gradation that would enable the use of this material as a lightweight aggregate.

One of the criteria used to characterize lightweight aggregate for use in CMU's has been a set of gradation curves developed by Besser, Inc. a major manufacturer of block making equipment². The Besser criteria was developed by compiling the size distribution of lightweight aggregate used by various block manufacturers, thus establishing a range of suitable size distributions that work well for producing lightweight CMU's. Since the criteria was developed for manufactured aggregate, it may not be applicable for bottom ash which is similar, but certainly not the same. The primary purpose of this investigation was to develop a simple method to evaluate aggregate for use in CMU's that would be based on the performance of the aggregate rather than a single criteria such as size distribution.

EXPERIMENTAL

Overview

Bottom ash from the Rockport Generating Station in Rockport, IN was used in this evaluation, a class C ash produced from the combustion of western U.S. sub-bituminous coal. The aggregate was evaluated in a 3 step process; density testing, cylinder testing for fly ash replacement and for cement content followed by lab scale CMU testing. The same suite of tests were then performed on two other ashes produced from eastern coals and the resulting F ashes.

Density testing

The entire bottom ash sample (300 lbs) was oven dried and screened to remove oversize particles (+3/8 inch). A representative portion was obtained by riffing and the size distribution was determined by dry sieve analysis. The entire sample was then screened into the various size fractions required by ASTM gradation specifications (4, 8, 16, 30, 50 and 100 mesh).

Density testing was conducted by combining the size fractions in a variety of proportions and compacting samples using a laboratory device that simulated the mechanical functions used during commercial block making; compaction and vibration. The device (Figure 1) consisted of a pneumatic piston mounted on a plate equipped with a pneumatic vibrator. Separate controls allowed for independent control of compaction and vibration during testing. A standard 1/30 cubic foot proctor mold was loosely filled in one lift with the aggregate and subjected to a compactive effort exerted by a pneumatic piston. Vibration was applied during compaction and the height of the compacted aggregate was measured to determine the compacted density.

The compacted density was plotted against the fineness modulus of the aggregate for several gradations, Besser curves, as received, .45 power curve³, etc, in a similar manner used for standard proctor testing (Figure 2). An aggregate gradation with a Fineness Modulus of 3.2 provided the highest density of all the size distributions tested. Since all the size fractions were of similar density, a higher density in the test would provide a gradation that would have less air voids allowing cement to bond the aggregate rather than fill voids.



Figure 1. Laboratory-scale pneumatic piston with vibrator.

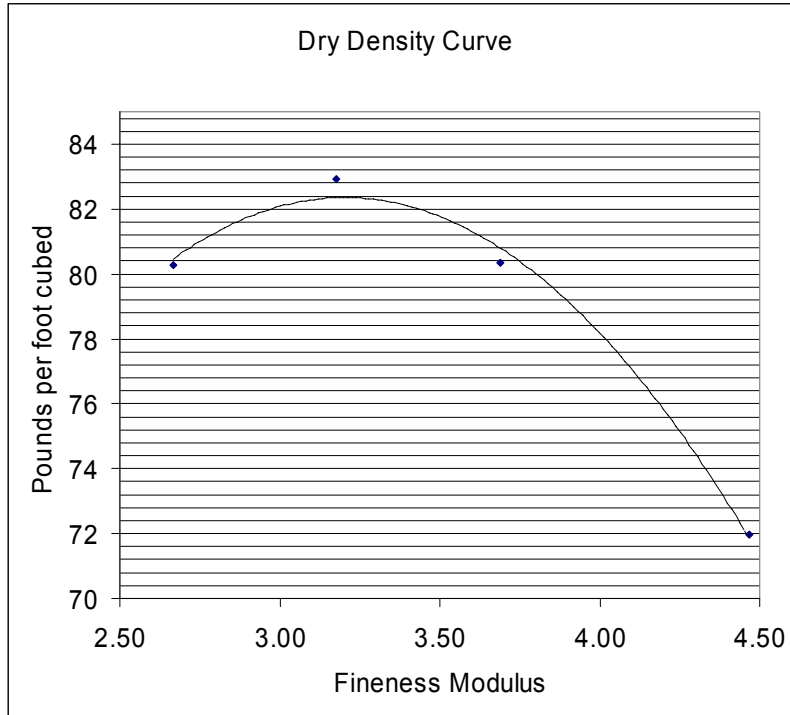


Figure 2. Effect of Fineness Modulus on Density.

This procedure was then repeated samples with the same gradation and varying moisture to determine the optimum moisture content. Dry samples were combined with the appropriate amounts of water in sealed plastic bags, thoroughly mixed and allowed to equilibrate for 24 hours before testing. The results (Figure 3) showed that maximum compaction was achieved at a moisture content of 6%. While this moisture content appeared to be wetter than Surface Saturated Dryness (SSD), it was used in mix design calculations to be certain that the aggregate was adequately wetted prior to the addition of cement and additional water to maintain consistent water to cement ratios

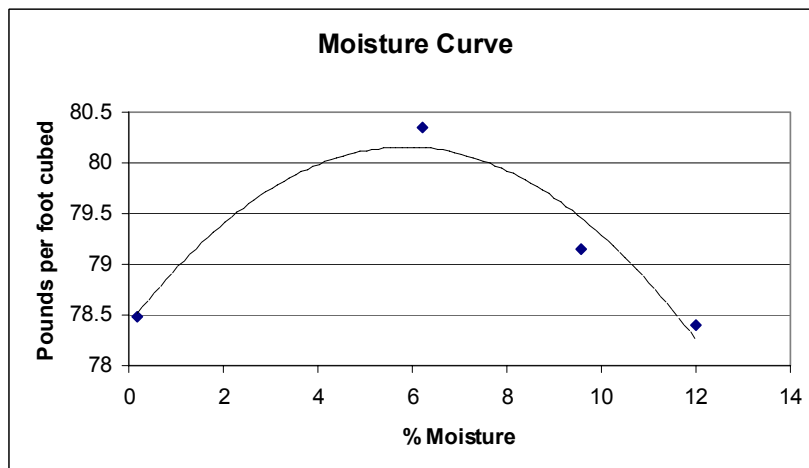


Figure 3. Effect of Moisture on Density.

Cylinder testing

The appropriate size fractions of dry bottom ash and water to achieve the desired maximum compacted density were combined in a vertical shaft mixer, thoroughly mixed and allowed to equilibrate for 15 minutes. Cement was then added to the mix followed by the necessary amount of water to achieve the desired workability. The mix was then transferred to standard 3 inch diameter concrete molds, filled in one lift, consolidated by vibration, and compacted by the pneumatic piston. Samples were then cured in a humidified lab scale curing cabinet (Figure 4) for 24 hours, after which the samples were removed from the cylinder molds. Capped with a sulfur capping compound and returned to the curing cabinet. Cylinders were evaluated for compressive strength testing after 3, 7, 14, and 28 days. Results are reported as averages of three specimens.



Figure 4. Capped cylinders in curing cabinet.

RESULTS AND DISCUSSION

For initial testing, cylinders were prepared using the gradation that provided the maximum compaction described previously. A cement to aggregate ratio of 1 to 6 was selected based on preliminary evaluations and maintained during this phase of testing. Other mixes were prepared using increasing proportions of Class F or Class C fly ash. The results are shown in Figures 5 and 6.

When using Class F ash (Figure 5), the compressive strength increased as the amount of fly ash was increased from 0 to 30%. Higher replacement levels did not provide additional strength development. The desired target strength of 1000 psi after 3 days curing was achieved only with 30% fly ash substitution. Lower fly ash replacement amounts provided acceptable strengths after 7 days and when no fly ash was used, a compressive strength of only 700 psi was achieved after 28 days. These results clearly show that it is necessary to use fly ash along with bottom ash to achieve desired early strength development.

For Class C ash (Figure 6), similar trends resulted, however the strengths were much higher. After 3 days of curing, increasing the amount of Class C ash from 0 to 30% increased the strength from 450 psi to 2200 psi, more than double the target strength. After 7 days, 30% Class C ash provided cylinder strengths of 3000 psi. These results show that Class C ash provides early strength development attributed to the additional cementitious properties of the ash.

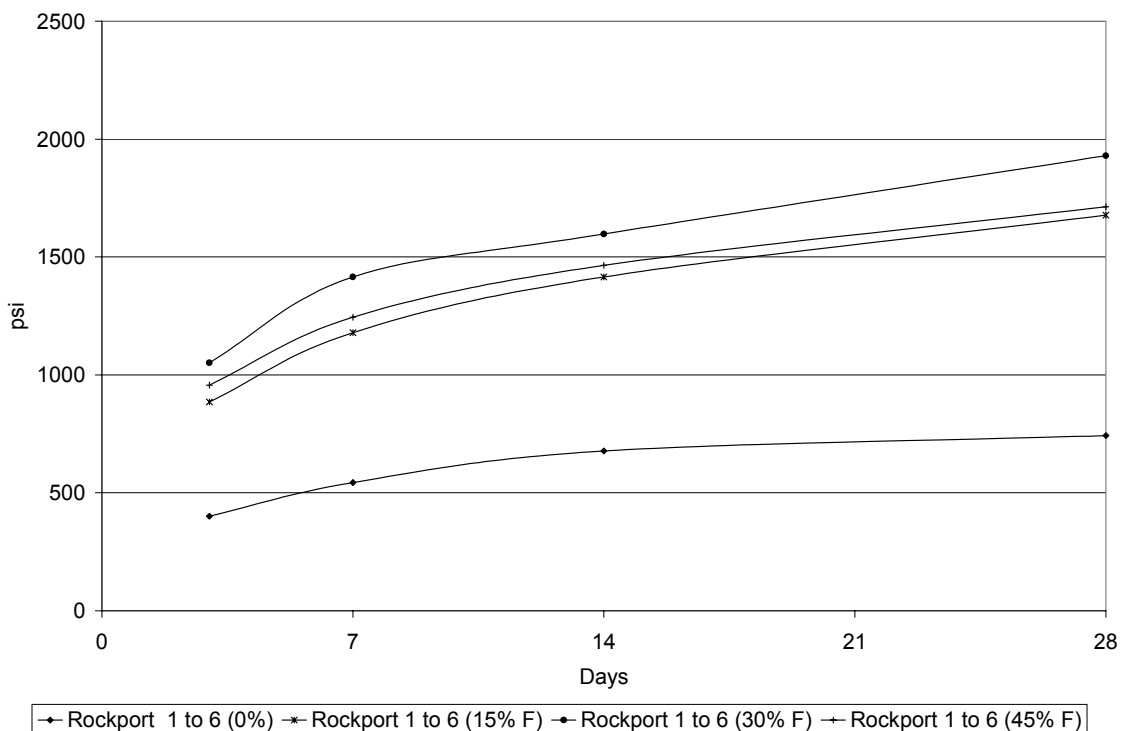


Figure 5. Effect of curing time on cylinder strength for varying amounts of Class F fly ash.

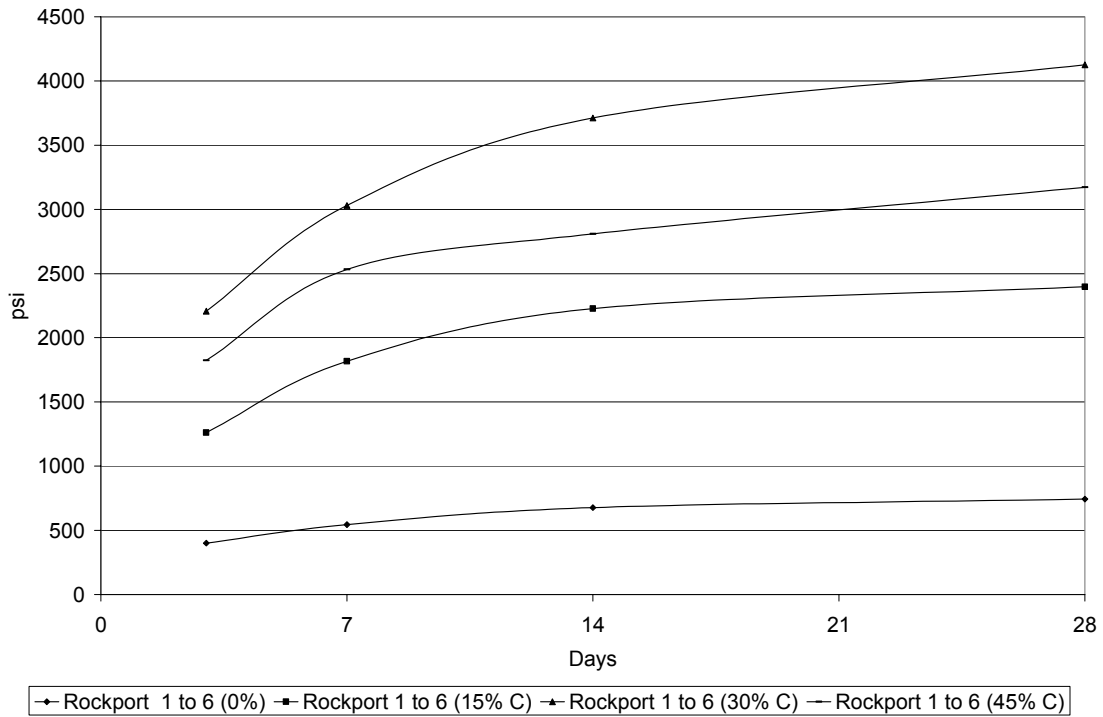


Figure 6. Effect of curing time on cylinder strength for varying amounts of Class C fly ash.

Since the cylinder strengths using Class C ash were much higher than the target strengths, a second round of testing was performed to determine how low of a cement to aggregate ratio could be used and still meet the target strength. The results (Figure 7) show that reducing the cement to aggregate ratio from 1 to 6 to 1 to 8 diminished strength from 2200 psi to 1300 psi. The 3-day target strength was maintained using 25% less cement, the most costly component of the mix design.

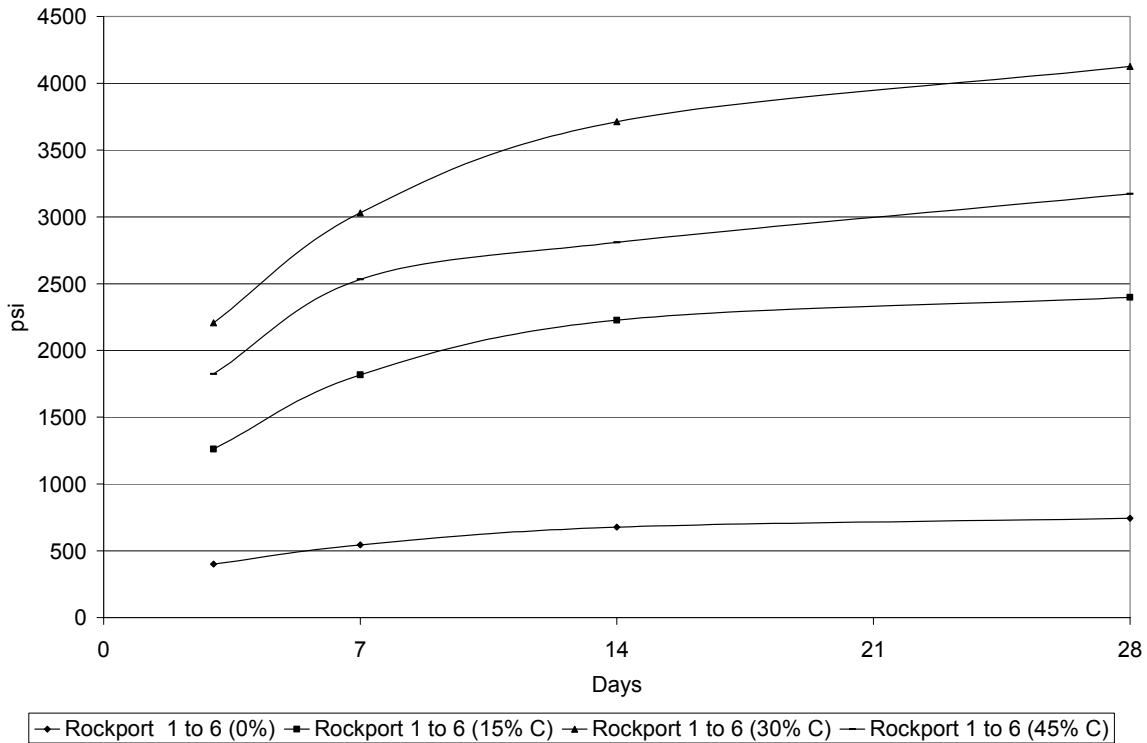


Figure 7. Effect of curing time on cylinder strength for 30% Class C fly ash and varying cement to aggregate ratios.

The final phase of testing involved producing CMU's in the lab from the mix designs used in cylinder tests. The same procedures were followed for making the block as were used for making the cylinders. The results (Figure 8) show that strengths obtained from cylinders were much higher than those obtained from blocks. There are several possible reasons for these differences. Most obvious is that the block machine used has no independent control of either the compaction or vibration mechanisms. Despite repeated efforts, it was not possible to modify the block machine to produce results consistent with those provided by the cylinders. More likely however, is that when the batch size was increased, the fly ash in the mix began to pelletize. These pellets are another possible reason for the lower strengths in the block since the agglomeration of the fine particles effectively changed the gradation of the mix and made it difficult to actually fill the block mold since the size of some of the pellets were so large.

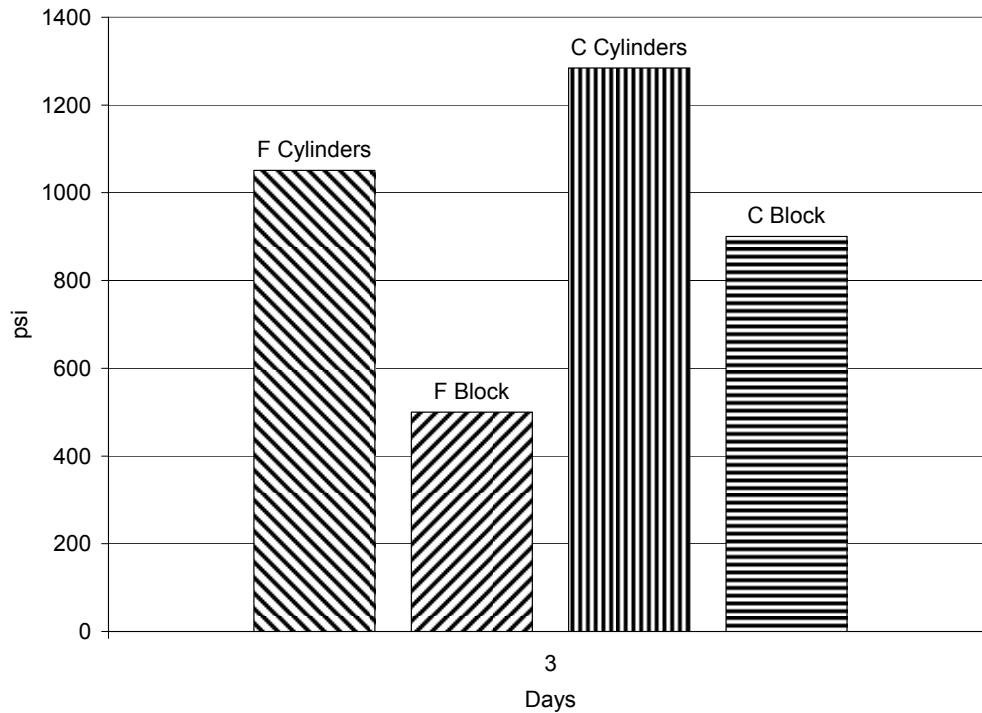


Figure 8. Comparison of cylinder and block specimens after 3 days of curing.

CONCLUSIONS

A laboratory test procedure has been developed to evaluate the use of combustion bottom ash as aggregate in CMU's. The procedure enables the evaluation of test cylinders rather than blocks which requires significantly less material. Manipulation of the size distribution of bottom ash enables higher levels of compaction to be achieved, which should lead to higher compressive strengths at fixed amounts of cement since there are less voids.

Rockport bottom ash, when used alone as an aggregate, did not achieve the target strength requirements of 1000 psi in 3 days.

Substitution of fly ash for aggregate improved compressive strength for cylinder specimens. Fly ash substitution levels of up to 30% Class C or Class F fly ash were beneficial for strength development.

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