Effects of Kaolin on Engineering Properties of Portland Cement Concrete

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EFFECTS OF KAOLIN ON THE ENGINEERING PROPERTIES OF PORTLAND CEMENT CONCRETE

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Abstract: The focus of this study was to determine the feasibility of using kaolin, a very small particle clay, as partial replacement of fine aggregates in Portland cement concrete (PCC). Kaolin clay is a locally available (Macon, GA, USA) and inexpensive clay mineral. The product, KaMin 90©, used has an average particle size of 1.5 microns and has a low embodied energy. The slump, air void content and compressive strength were examined on samples of PCC with different % of Kaolin. This research indicated the maximum kaolin substitution of fine aggregate for workability. An optimal dosage range for PCC cylinder compressive strength was also defined and found to be 33% greater than the control group. It was also noted that Kaolin engenders a soft and cohesive concrete mix that prevents segregation. A brief cost analyses was performed and determined the economic feasibility of Kaolin PCC.

Introduction

Concretes high compressive strength, onsite casting and adaptability, when compared to steel, lend Portland cement concrete (PCC) its popularity. Portland cement concrete is a 17 billon dollar a year industry in the USA and is the third in global production just right behind water and electricity. Different mix designs with various materials and technologies have been used to alter strength as well as save cost. Portland cement, coarse aggregate, fine aggregate and water are the basic building components of the PCC. Every year, there are huge demands on the components raw materials for the production of the PCC, turning into to extensive exploring natural resources. Efforts have been made to us recycled, cheaper, environment-friendly materials worldwide to produce durable, high strength, life cycle cost effective long-lasting concrete. Therefore, it is always encouraged that we can find new technologies for concrete industry.

It is thought that kaolin will be beneficial to some properties of Portland cement concrete (both fresh and hardened) such as segregation and compressive strength since the particles of Kaolin are fine. When it is wet, it is stick, preventing the segregation and suspending the aggregate uniformly. The detrimental effect of replacing fine aggregate with kaolin is the slump loss. The research is to be conducted in such a way as to determine the working limits of kaolin; so that the results can be contributed to cretin property changes in the concrete slurry.

The objectives of this research are

1) To determine the effects of Kaolin clay on concrete's engineering properties such as compressive strength and slump.
2) To determine the working limits of the materials added as a substitute of fine aggregates.

Materials Used and Test Methods

Over the scope of the work consistent materials were used. All the aggregates used came from a single delivery. The aggregates were tested for consistent gradation and kept in the original sealed containers to maintain consistent moisture content. The cement was type I/II Portland cement from a single source. All of the kaolin products used were from the same container with consistent particle size. The ASTM methods are followed for the testing.

1. ASTM C566-Moisture content of aggregate, was followed for the determination of moisture.
2. ASTM C136-Sieve analysis of fine and coarse aggregates, was followed for the aggregate gradation analysis.
3. ASTM C143/C143 M- Slump of hydraulic-cement concrete, was followed to determine whether a concrete slurry is workable, able to be moved and placed without segregating or to stiff to be settled
4. ASTM C231-09-Air content of freshly mixed concrete by the pressure method, was followed to determine the percent volume of air trapped in placed concrete slurry.
5. ASTM C 39/39M–05-Compressive strength of cylindrical concrete specimens, was followed to determine the compressive strength for all samples.

Table-1 listed the properties of the materials used. Figure 1 is the SEM picture of kaolin. The PCC samples tested were produced with partial replacement of fine aggregate by Kaolin as a rate of 1, 2.5 and 5% in weight. PCC with no Kaolin were tested as control samples.

Table-1 The properties of the materials used for this project

	Portland Cement	**Kaolin**	**Fine Aggregate**	**Coarse aggregate**	**Water**
Type	Type I/II	Kaolin	Silica	Granite	Tap
Specific Gravity	3.17	2.6	2.6	2.75	1
Absorption capacity (%)	N/A	N/A	0.12	0.04	N/A
Moisture content (%)	0	0	3.34	0.52	N/A

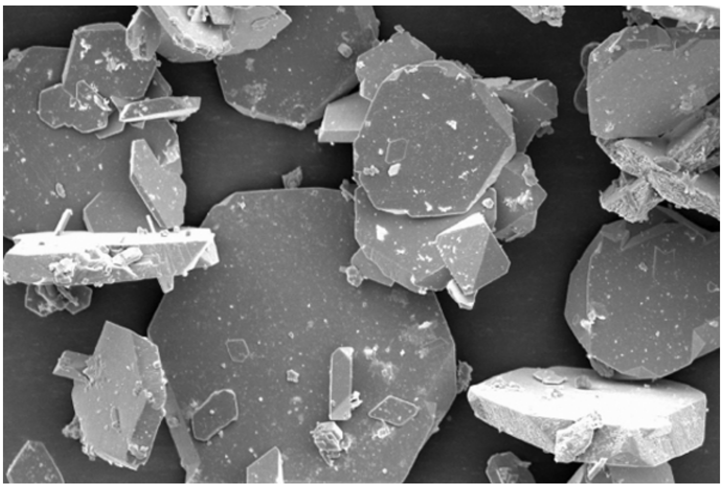

Figure 1 SEM of Kaolin

Results and Discussions

Particle Size

Many engineering properties of the modified concrete have been attributed to site effect (1, 2). For this reason care was taken to investigate these claims. Figure 2 displays the relative particle sizes of common concrete additives. Silica fume and micron 3© fly ash have had their high strength correlated to their fine particle size. Kaolin has a particle size between the fume and the fly ash. Kaolin (KaMin 90©) was thought to shift the gradation curve. But after closer examination of the gradation chart, the kaolin has little effect. Adding the fine Kaolin changed only the gradation of the very part of the fine aggregates, see Figure 3.

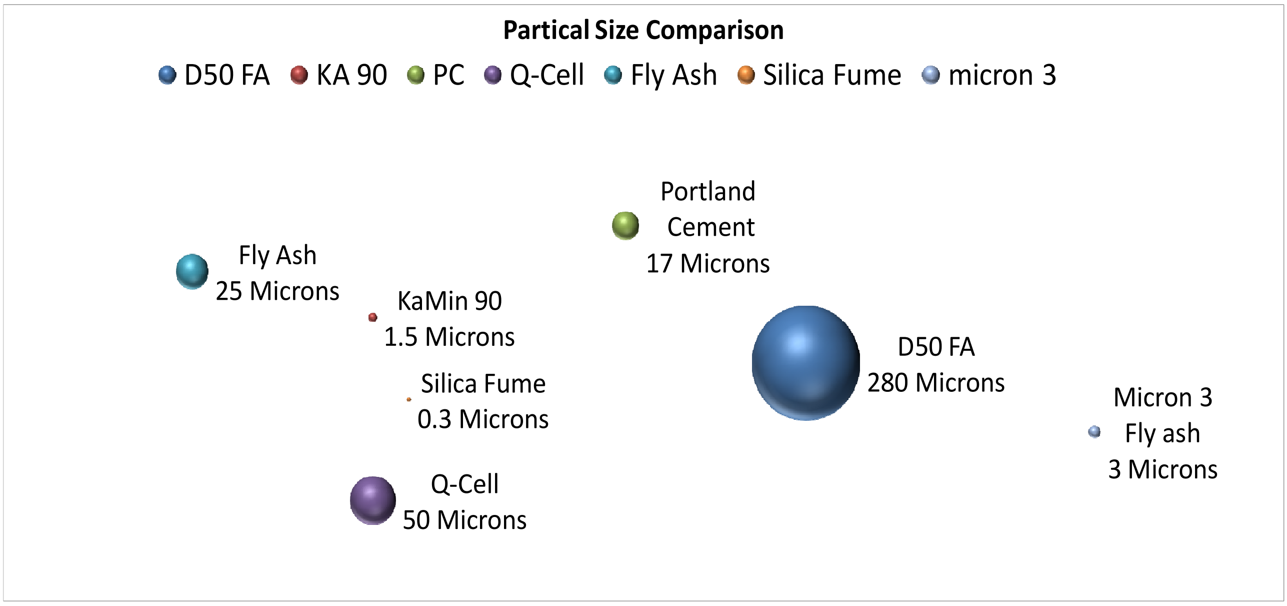

Figure 2 A comparison of particles of different additives

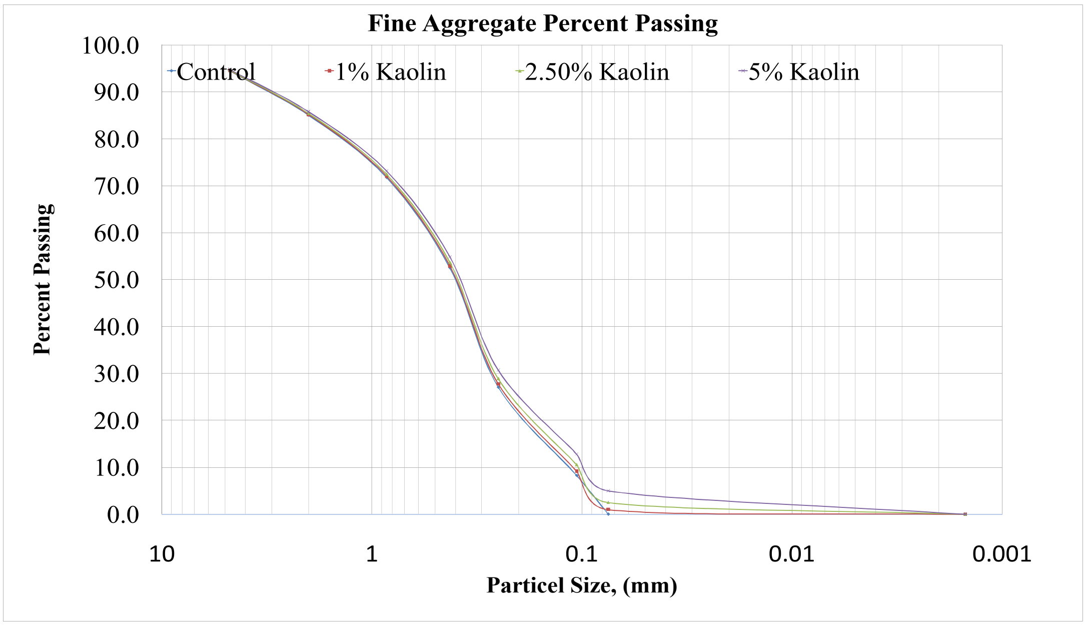

Figure 3 Gradation of fine aggregates with different of Kaolin replacement

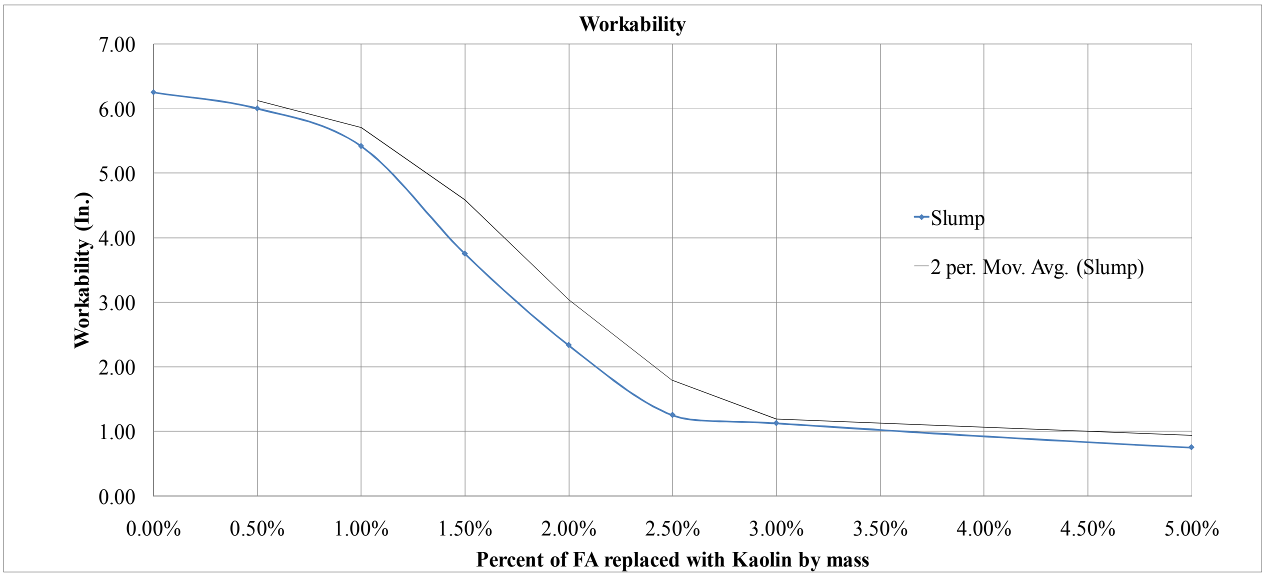

Figure 4 Slump of concrete with different % of kaolin

Slump & Air Void Discussion

Duplicate slump and air void tests were performed for each batch with different % of Kaolin. The slump results presented in Figure 4 show dramatic decrease when the ratio of Kaolin between 1 and 2.5% that was attributed to kaolin's high cohesion. The air void in the fresh concrete presented in the Figure 5 show a quick increased when the Kaolin was in this range, classified as a transition zone. Between these limits the slump deteriorates sharply and void ratio increases rapidly, both of which indicate the effectiveness of the addition of the Kaolin on the decrease of the slump. The stick paste resulted in a low slump and high void ratio of the fresh concrete.

The concrete mixture also begins to exhibit a thicker creamier texture as the % of Kaolin increases. The kaolin increases the viscosity of the mix, resulting in better suspending the aggregate. In addition, it physically bleaches the color of the cured concrete to a pleasant white. When higher amounts of kaolin are added (above 3%) the workability and air void contents begin to level out. The paste, a mix of Kaolin into the cement, water, fine aggregate exhibited a strong cohesive strength. The paste was capable of suspending upside down to a smooth surface, and held onto the coarse aggregate.

It should be noted that the slump number does not directly imply workability with a kaolin mix. Unlike common PCC, the kaolin has a high cohesion value. This cohesion prevents the concrete paste from achieving a high slump number unlike unmodified PCC paste. Inversely, kaolin gives normally grainy concrete paste a soft and smooth texture. Kaolin suspended in the paste, increases the spacing between fine aggregates and allows a nice texture. The cohesion also holds the coarse aggregate and prevents segregation of particles. This is believed to be the controlling influence in the strength chart.

Air content is measured by volume and as a percent of the total concrete sample. As the cohesion of the slurry increases it becomes increasingly more difficult for air to rise out of the mix. These air voids interrupt the strength matrix that forms between the coarse aggregate and paste, which results in lower compressive strength.

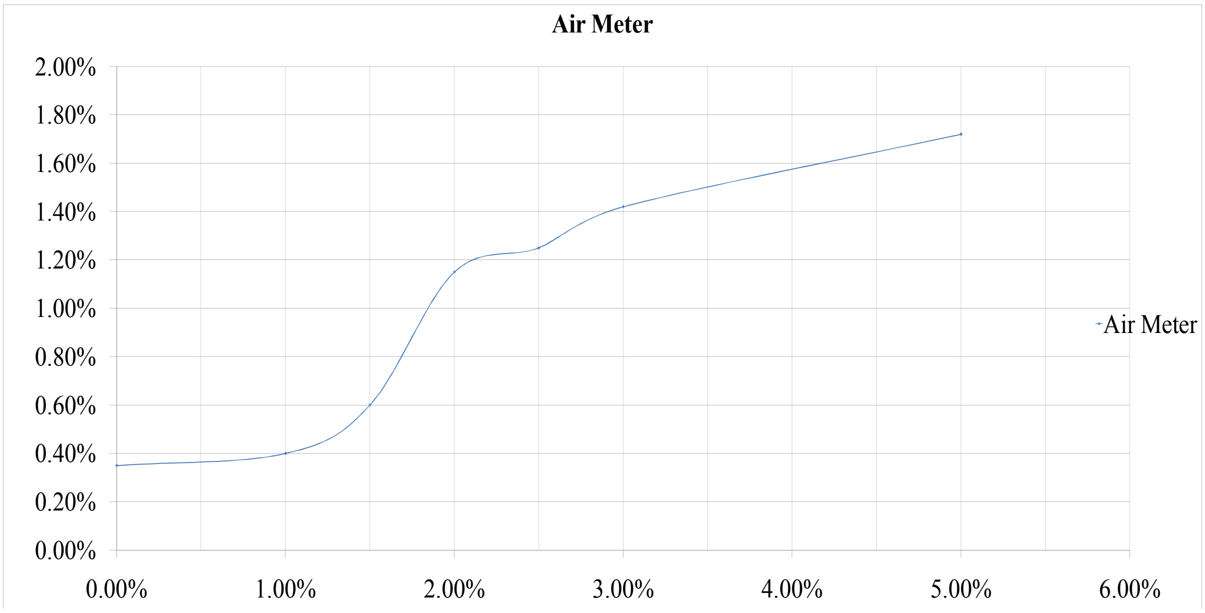

Figure 5 Air void of concrete with different % of Kaolin

Compressive strength

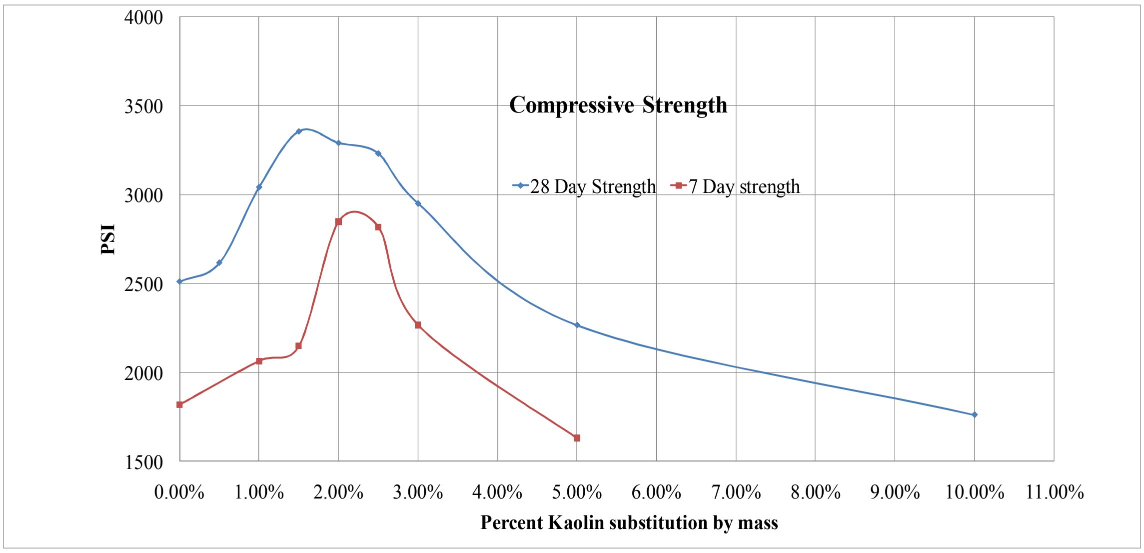

Figure 6 Compressive strength of the concrete with various % of Kaolin

The results have shown an increase in the overall compressive strength of PCC. From the compressive strength chart, 1 to 3% kaolin can be seen as the optimal range, while the maximum strength can be achieved at a % between the transition zone. The strength gain can be contributed to the particle size as well as kaolin's cohesive paste. Many studies have been conducted on the size effect of particles the strength of concrete and it is well understood that small particles help form a denser mix of aggregate and increase strength. The mechanism of the size effect has been examined elsewhere also. The "Gradation Curve" chart shows the small amount of kaolin has effected on the gradation of the fine aggregate, towards to a better gradation with the addition of the Kaolin. Besides, the increase in strength is contributed mainly to the unsegregated materials matrix and the transformed cement/kaolin paste. The cohesive paste formed when using Kaolin clay increases the spaces between sand particles and suspends the aggregates inside the paste. This allows the concrete to cure as intended, without the large particles settling to the bottom and stacking. In other words, the paste is formed uniformly and behaviors strongly.

The strength chart shows a decrease in strength starting at 2.5% kaolin. The dramatic transition zone (Air Void Chart) ends at 2.5%. Comparing the two charts does not reveal a linear correlation between strength and air voids. This indicates that the air voids are not the primary inhibiter of strength. It is not clear what interaction is causing this but it is clear that an over saturation of kaolin particles in the paste (as indicated with a low slump) is undesirable.

Modified Mixing Method

A modified mixing procedure was used in response to the high plasticity and cohesion of the kaolin. Mixing the fine aggregate, coarse aggregate, kaolin and cement prior to adding water caused the kaolin to encapsulate the aggregate. This was deemed strength inhibitive.

Kaolin is added after the water and initial mixing. This was done to keep the kaolin from coating the aggregate or clumping together. Concrete develops its strength between the cement and aggregate. Any contact between kaolin and aggregate is not beneficial. Early tests mixed the sand and kaolin before adding the cement water slurry. The surface moisture caused the kaolin to clump and encapsulate the fine aggregate. These results were thrown out and the new mix order was used.

Summery and Conclusions

Kaolin, basically a very fine, abundant clay available in local GA, USA, has been partially replaced for fine aggregates for PCC for better workability, high strength and better durability. A series tests were performed on the engineering properties of PCC with various % of Kaolin and control samples. Here are the main findings from limited preliminary study:

1. Kaolin Clay can increase the strength Of Portland Cement Concrete.
2. Kaolin substitution above 3% leads to high air void content. Slump and Air Void content have a transition zone is directly and inversely related to the other.
3. 1-3% Kaolin substitution was defined as the optimal strength range.
4. 2% Kaolin substitution was defined as the maximum working limit.
5. Creating a soft cohesive and viscous mix, it was discovered that Kaolin had a strong effect on the concrete slurry.
6. The results were attributed to this cohesive slurry and its' support of the slurry's particle matrix.
7. A simple study of cost estimates $3 USD of kaolin per yard of concrete to achieve best strength and working results

Acknowledgements

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