OPTIMIZATION OF FLY ASH IN CONCRETE: High Lime Fly Ash as a Replacement for Cement and Filler Material

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Abstract

This research paper seeks to optimize the benefits of using High Lime fly ash in concrete as a replacement for large proportions of cement.

High Lime fly ash is a type of sub-bituminous fly ash that is self-cementing as well as pozzolanic in nature. High Lime fly ash would be categorized as a Class C fly ash by ASTM because of its high calcium content, however its sulfur content exceeds the limit set in ASTM C618[2]. The physical and chemical properties of this type of fly ash, particularly its fineness and carbon content properties (coarser particles and low carbon content), provide potential benefits. These two properties are of great concern since they will affect the air content and water demand of the concrete; parameters that greatly affect the durability and strength of concrete.

This paper describes early stages of a project to study the use of large volumes of High Lime fly ash in concrete. During the project High Lime fly ash obtained from a local power plant will be used in the concrete tests. Varying amounts of fly ash will be used in given mixes of concrete as a partial replacement of the cement (binder) and fine aggregate (filler). Several design mixes will be prepared, cured and tested for their compressive and bond strengths, and durability (freeze-thaw) properties. Each compressive strength sample will be tested at 3, 7, 14, 28 and 56 days. The results will be analyzed and compared with standard concrete and conclusions made on how best the fly ash can be utilized to give optimum results.

The results presented in this paper address preliminary results for the compressive strength tests. The tests provided a general increase in the strength of concrete with addition of High Lime fly ash. The test results indicate that replacing proportions of cement with High Lime fly ash would provide improved strength and a most cost effective solution.

Keywords: High Lime Fly ash, concrete, compressive strength

Introduction

Fly ash is a residual material of energy production using coal, which has been found to have numerous advantages for use in the concrete industry. Some of the advantages include improved workability, reduced permeability, increased ultimate strength, reduced bleeding, better surface finish and reduced heat of hydration [1]. For several years it has been used in varying proportions and compositions in concrete. Research indicates that there are still additional benefits to be gained if the concrete industry can further optimize its use in concrete.

Several types of fly ash are produced depending on the type of coal and the coal combustion process. It is a pozzolanic material and has been classified into two classes, F and C, based on the chemical composition of the fly ash. The fly ash being used for this research contains significant amounts of lime and would be categorized as a Class C fly ash with the exception of sulfur amounts that do not conform to the ASTM classification [2] of class C fly ash.

Portland cement is composed of free lime and siliceous and aluminous materials (pozzolans), which in the presence of water, will chemically react with the calcium hydroxide released by the hydration process to form a cementitious paste that binds the inert materials in the concrete [10]. Fly ash is also a pozzolanic material but with different amounts of the constituents. The fly ash being used for this study contains significant amounts of lime, which reacts with the pozzolans within itself forming (hydrated) calcium silicate gel or calcium aluminate gel (cementitious material) which bind the inert material together, making it self-cementing.

All fly ashes have a particle size ranging less than 0.075 mm [1]. The fineness and lime content properties of the fly ash are of great concern since they will affect the air content and water demand of the concrete; parameters that greatly affect the durability and strength of concrete respectively.

This research seeks to optimize the use of fly ash by taking advantage of the properties of High Lime fly ash to produce concrete with improved results and added benefits. A series of tests will be carried out, analyzed and compared to concrete manufactured with only Portland cement as a binder. The tests to be done will focus on the compressive strength, durability and bond strength properties of concrete. The results presented in this paper are the preliminary results of the research, discussing the compressive strength test results and partial results for the durability testing.

Materials and Testing

Fly Ash

High Lime fly ash obtained from a local power plant was used in this project. The specific gravity of the fly ash used was 2.71 g/cc. This fly ash had a significant amount of lime at 23.65 percent and a sulfur trioxide content of 6.19 percent, which exceeds the ASTM C618[2] limits for Class C fly ashes for use in concrete, as shown in Table 1. At the initial stages, this project has focused more on the positive utility of the high lime and very little concern has been given to the high sulfur content. However the effect of sulfur on the durability of the concrete will be considered at later stages of this project.

Table 1: Partial Chemical Composition of the High Lime fly ash used, (SGS North America,Inc)

Chemical Analysis	SiO_2	Al_2O_3	Fe_2O_3	CaO	SO_3	LOI
Fly Ash Composition (%)	39.76	14.31	5.56	23.45	6.19	1.65
ASTM requirement (%)	Total >50			-	<5.0	<6.0

Concrete

Compressive Strength

The concrete was designed using the PCA Absolute Volume Method for a design strength [9] (at 28 days) of 4500 psi (31MPa) with a target strength of 5700psi (39MPa) and a slump ranging between 1 - 3 inches (25 – 75mm) hence a water/cementitious ratio of 0.525 was used. The concrete mixes were made using Type I/II cement and without the use of any water reducers. They were prepared and batched by weight with varying percentages of fly ash added to replace varying percentages of the cement and fine aggregates, as shown in Table 2. For this work the effect of varying amounts of fly ash replacement was the variable of interest, however, following the Portland Cement Association (PCA) design approach [9] also required small adjustments to the amount of fine aggregate. Further research could possibly consider the replacement of fine aggregate by fly ash.

Table 2: Non –air entrained Concrete Mixes (Design Strength 4500psi (31MPa))

Parameter	**Control**	**Mix 1**	**Mix 2**	**Mix 3**	**Mix 4**	**Mix 5**	**Mix 6**	**Mix 7**	**Mix 8**
Fly Ash (%)	0	15	20	25	30	35	40	45	50
Water (lb)	324	324	324	324	323	323	323	323	323
Cement (lb)	648	550	518	486	453	421	389	356	324
Fly ash (lb)	0	97	130	162	194	227	259	291	324
Coarse agg (lb)	1,707	1,707	1,707	1,707	1,707	1,707	1,707	1,707	1,707
Fine agg (lb)	1,279	1,265	1,261	1,256	1,252	1,248	1,243	1,239	1,234

The concrete for the compressive strength tests was prepared and tested according to ASTM C192, C39 and C150 [3], [4], [5]. Both metal and plastic cylinders that conform to ASTM C39 were used. A small concrete mixer was used to prepare the concrete and three cylinders were manufactured for each point required to be tested. The concrete samples were moist cured at a 99% humidity level and each mix was tested at 3, 7, 14, 28 and 56 days after curing. The results of the three cylinder tests were averaged for each point and tabulated.

Durability

Air entrainers were added to the concrete used in the durability (freeze-thaw) test. The same target design strength of 4500psi (31MPa) was used for this test. In order to reach the same design strength in the presence of air entrainers the water/cementitious material ratio was adjusted to 0.44. This was necessary because air entrainers increase the voids ratio, hence requiring a lower water/cement ratio. Trial mixes were carried out to estimate the amount of air entraining agent needed for the no-fly ash, 30%, 40% and 50% fly ash concrete mixes, which were chosen for the durability test. Varying amounts of air entrainer were added to each trial mix; a sample of the concrete was taken out from each and was tested for the air content using the volumetric method [7] and air indicator kit [8]. This test procedure was repeated several times until an air content of 5% was attained. The amount of air entrainer that provided the 5% air content was noted as the sufficient amount. This amount of air entrainer used ranged between 5.5 – 17 fl. oz (170 - 500 ml) per 100 lbs (45.36kg) of cementitious material. Due to the fineness of the fly ash (the finer, the lesser the voids), the concrete with additional fly ash required more air-entraining agent to give the mix the desired air content.

Concrete prisms were then prepared according to ASTM C 666 [6], in preparation for the freeze thaw testing yet to be completed.

Results and Discussion

Compressive Strength

The compressive strength of concrete is one of the most important design parameters required for concrete. This series of tests determines the strength attained by concrete whose cement and fine aggregate quantities have been replaced with fly ash varying from 0 to 50 %. The compressive strength tests were carried out in accordance to ASTM C 39[4] and C192 [3]. The results plotted on the graphs below are the average values of three cylinders tested at each age and fly ash percentage.

Compressive Strength vs. Fly Ash Percentage

As more fly ash is added to the concrete, a decrease in the rate of strength gain is observed as shown in Figure 1. Early strength gain (within the first 3 – 7 days) generally decreases as more fly ash is added to the concrete. Fly ash affects the early strength gain probably due to the free lime that is still reacting during the curing process. As the concrete is further cured, the ultimate desired strength is attained at 56 days.

Concrete with 25 – 35% fly ash provided the most optimal results for its compressive strength, as shown in Figure 1. This is probably because the fly ash provides adequate lime needed to react with the pozzolans in the hydration process. More lime seems to inhibit the hydration process, but yet is still adequate to provide the needed design strength.

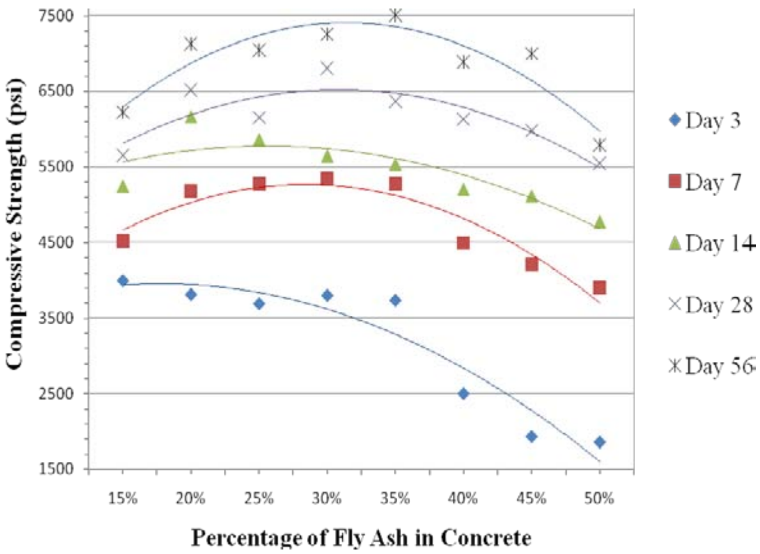

Figure 1: Compressive Strength against Fly Ash Percentage

The results for the day 56 for the 45% and 50 % fly ash replacement have been projected, since results are not yet available.

Fly Ash vs. Age of Concrete

The results presented in figure 2 below represent the general trends of the results. The compressive strength of the fly ash concrete increased with an increase in the number of days that it was cured. With a further increase in fly ash beyond the optimal value (beyond 35% fly ash replacement), the concrete attains a low rate of strength development within the first 3 days (as shown in figure 2 for 40 % and 50 % trend lines). The strength accelerates within the next 7 days then follows a similar trend in strength gain with the rest of the samples (Figure 2).

Both concrete with and without fly ash attained about 70 – 80% of its strength within the first 7 days of curing. At 28 days all the mixes had attained the required design strength of 4500psi (31MPa).

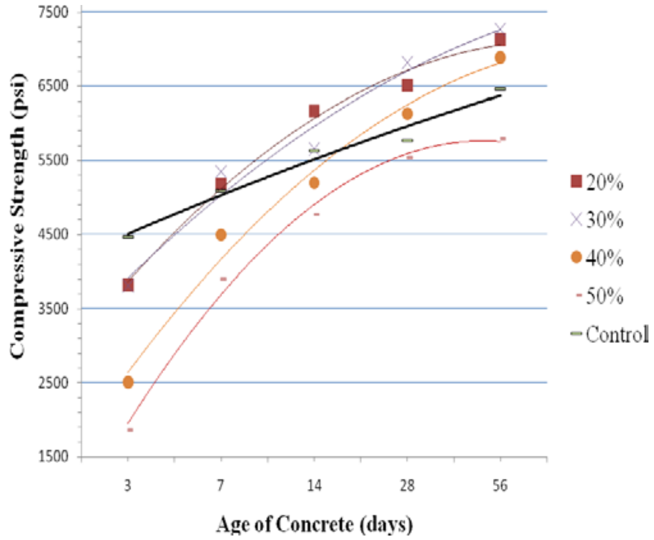

Figure 2: Compressive Strength against Age of Concrete

Durability (Freeze-thaw) tests

About 5.5 – 17 fl. oz (170 - 500 ml) of air entrainer per 100 lbs (45.36kg) of cementitious material was used in the mixes to provide a 5 percent air content. The air entrained mixes have been moist cured and will be tested at 14 days after curing. They will be subjected to repeated cycles of freezing and thawing and tested according to ASTM C 666[6]. Results attained from the tests will assist in determining the relative dynamic modulus of elasticity and durability factor. These parameters will be compared against the acceptable limits for concrete subjected to freeze-thaw conditions.

Conclusion

The following conclusions can be drawn from the work completed to date:

1. Replacement of high lime fly ash in concrete generally increases the ultimate strength of concrete.
2. It is probable that even higher percentile replacements of cement would still be able to provide the same compressive strength as no-fly ash concrete (the fineness of fly ash and the high lime amounts provides a much better hydration process of the pozzolanic reactions,

hence increased strength gain). However, the results of this study do not indicate at which point the continued replacement of cement with fly ash would cause the compressive strength to decline below the strength observed from the no-fly ash concrete.

3. A 25 - 35 % fly ash replacement provides the most optimal (best possible) strength results. Beyond 35 % fly ash replacement, the rate of gain of compressive strength decreases but maintains its strength value above the desired design strength.
4. Replacement of cement with high lime fly ash reduces the rate of strength development/ gain, beyond the optimal limits obtained for 25 – 35 % fly ash mixes.
5. More air entrainer admixture is required for increasing amounts of fly ash used.

This paper describes preliminary results of an ongoing project. More research work is being carried out to determine the effects this fly ash would have on the durability and bond strength of concrete.

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