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Analysis of Fly Ash Cement Concrete for Road Construction

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Abstract

This experiment study aimed to investigate the physical, chemical and mechanical properties of fly ash cement concrete for road construction. Research has shown that 30% of fly ash and 70% of cement has a superior performance. Characteristics compared to the standard requirements conformable code. Moreover, the use of fly ash would result in reduction of the cost of materials in construction and the reduction of greenhouse gas emission. High strength of concrete can be made and the incorporation of admixture or substitute to improve the properties of concrete. Test result of specimens indicates the workability, and bonding strength of properties, and different reaction when the water ratio a change its content. Slump test having an appropriate workable mixing the slump of a concrete, gave sufficient compressive strength. Test results of 14 days specimens having different results but it only treated when it downs to minimum level of required conformable code.

Keywords: *Fly ash, concrete mixture, construction material, road pavement*

1. Introduction

Fly ash concrete was first used in the U.S. in 1929 for the Hoover Dam, where engineers found that it allowed for less total cement [1]. And the major breakthrough in using fly ash in concrete was the construction of Hungry Horse Dam in 1948, utilizing 120,000 metric tons of fly ash [1]. This decision by the U.S. Bureau of Reclamation paved the way for using fly ash in concrete constructions. It is now used across the country. Consisting mostly of silica, alumina and iron, fly ash is a "pozzolan" which is a substance containing aluminous and siliceous material that forms cement in the presence of water [2, 3]. When mixed with lime and water it forms a compound similar to Portland cement. The spherical shape of the particles reduces internal friction thereby increasing the concrete's consistency and mobility, permitting longer pumping distances. Improved workability means less water is needed, resulting in less segregation of the mixture. Although fly ash cement itself is less dense than Portland cement, the produced concrete is denser and results in a smoother surface with sharper detail.

Class F fly ash, with particles covered in a kind of melted glass, greatly reduces the risk of expansion due to sulfate attack, as may occur in fertilized soils or near coastal areas. Class C fly ash is also resistant to expansion from chemical attack, has a higher percentage of calcium oxide, and is more commonly used for structural concrete [4, 23]. Although the Federal government has been using the material for decades, smaller and residential contractors are less familiar with fly ash concrete [4, 22]. Competition from cement is one consideration. Because fly ash comes from various operations in different regions, its mineral makeup may not be consistent; this may cause its properties to vary, depending on the quality control of the manufacturer. There are some concerns about freeze/thaw performance and a tendency to effloresce, especially when used as a complete replacement for Portland cement.

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Fly ash has been successfully used as a mineral admixture in PCC for nearly 60 years [6]. This is the largest single use of fly ash. It can also be used as a feed material for producing Portland cement and as a component of a Portland-pozzolan blended cement. It must be in a dry form when used as a mineral admixture [7, 8]. Fly ash quality must be closely monitored when the material is used in PCC. Fineness, loss on ignition, and chemical content are the most important characteristics of fly ash affecting its use in concrete. Fly ash used in concrete must also have sufficient pozzolanic reactivity and must be of consistent quality.

Fly ash has also been used as substitute mineral filler in asphalt paving mixtures for many years. Mineral filler in asphalt paving mixtures consists of particles, less than 0.075 mm (No. 200 sieve) in size, that fill the voids in a paving mix and serve to improve the cohesion of the binder (asphalt cement) and the stability of the mixture. Most fly ash sources are capable of meeting the gradation (minus .075 mm) requirements and other pertinent physical (non-plastic) and chemical (organic content) requirements of mineral filler specifications. It must also be in a dry form for use as mineral filler [9, 14]. Fly ash that is collected dry and stored in silos requires no additional processing. It is possible that some sources of fly ash that have a high lime (CaO) content may also be useful as an anti-stripping agent in asphalt paving mixes [10, 11].

Fly ash has been used in flowable fill applications as a fine aggregate and (because of its pozzolanic properties) as a supplement to or replacement for the cement [12, 13, 15]. Flowable fill is a slurry mixture consisting of sand or other fine aggregate material and a cementitious binder that is normally used as substitute for a compacted earth backfill. Either pozzolanic or self-cementing fly ash can be used in flowable fill. When large quantities of pozzolanic fly ash are added, the fly ash can act as both fine aggregate and part of the cementitious matrix. Self-cementing fly ash is used in smaller quantities as part of the binder in place of cement. The quality of fly ash used in flowable fill applications need not be as strictly controlled as in other cementitious applications. Both dry and reclaimed ash from settling ponds can be used. No special processing of fly ash is required prior to use.

Also, fly ash has been used for several decades as an embankment or structural fill material, particularly in Europe [16, 17]. There has been relatively limited use of fly ash as an embankment material in this country, although its use in this application is becoming more widely accepted. As an embankment or fill material, fly ash is used as a substitute for natural soils. Fly ash in this application must be stockpiled and conditioned to its optimum moisture content to ensure that the material is not too dry and dusty or too wet and unmanageable. When fly ash is at or near its optimum moisture content, it can be compacted to its maximum density and will perform in an equivalent manner to well compacted soil.

Researchers have discovered that fly ash can substitute significant proportions of Portland cement, a key component in manufacturing concrete [5, 18]. Concrete is the world's most commonly used construction material, surpassing steel, wood and aluminum combined. Currently, 5 to 7 percent of the world's GHG emissions have been attributed to cement and concrete production [8, 19].

Due to the continuous operation of coal fired power plant producing waste combustion products, particularly fly ash that earns much protest of our environmentally conscious society, the study gives way in the recognition of using fly ash as an additive to concrete mixture in the construction industry particularly in concrete road construction [20, 21].

This study lessens the problem in the reduction of greenhouse gas emission and avoids landfill disposal of ash products. Also, it helps in the improvement of concrete mixture as road base materials. In its whole, the research study addresses the interest of the ecosystem and the construction and building technology to enhance the natural world as well as that of the construction materials.

The results of this study are expected to benefit also the following: a) Researchers: to discover new knowledge and encourage other researchers to conduct similar studies about the waste combustion products usage in other industries; and b) Government: to provide ideas on the potential usage of fly ash as a construction material and to provide funds to further develop the study that might help in the advancement of the technology and preservation of our environment.

2. Methodology

2.1. Project Design

The research will have two types of specimens, the mixture of fly ash and Portland cement road pavement and the plain Portland cement road pavement. To be able to develop such specimens, different processes shall be done including the testing processes the specimen might undergo. Fly ash, Portland cement, aggregates and water will be the materials of the first specimen and the same materials needed for the second specimen but this time fly ash is not included. These materials are collected or gathered first and the use of shovels, the materials will be mixed together with certain proportioning. By the time the materials are mixed, the rectangular and cylindrical molds must already be prepared. But first, take samples from the mixture which will be used for the slump test. After the mixing process, the mixture will be placed in the molds. A total of twelve rectangular specimens and twelve cylindrical specimens are going to made, six in each type and two specimens in each type are going to be tested for its compressive and tensile stress. Then the specimens undergo the curing process for the purpose of hydration. During the 7th, 14th, and 21st day, the molds will be removed, and by this time, the specimens will be tested. Test results will be obtained, and then interpretation must be done.

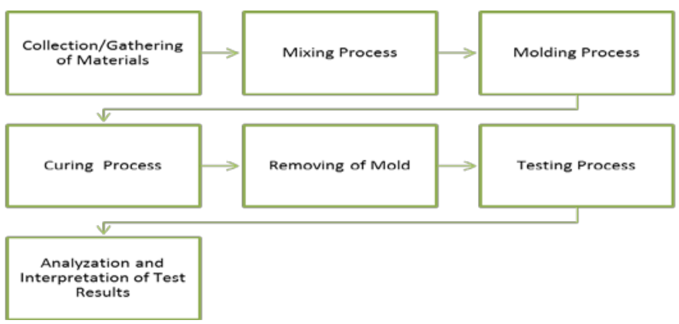

Figure 1. Project Design

2.2. Project Development

The research is all about developing fly ash for concrete road pavement. Different tests will be done so that the researcher could differentiate the proposed project from an ordinary cement-concrete mixture. The proposed project will be fly cement concrete mixture and plain cement concrete mixture. First part of the research would be the collection or gathering of the materials. The materials to be used in this research are sand, gravel, Portland cement, fly ash and water. The gravel is a combination of 3/8”, ¾” and ½” sizes. Specific gravity of fly ash would be obtained by using pycnometer. The determination of specific gravity will also determine the percentage of void. The consistency of the mixture is then tested by slump test. If the slump of the mixture is larger than the required, then change the mixture proportioning. If the flexural and compressive strength of fly ash and Portland cement specimens are higher than the Portland cement specimens, then the mixture of fly ash and Portland cement is more efficient in terms of road construction compared to the plain Portland cement. On the other hand, if it is lower, the mixture proportioning must be changed.

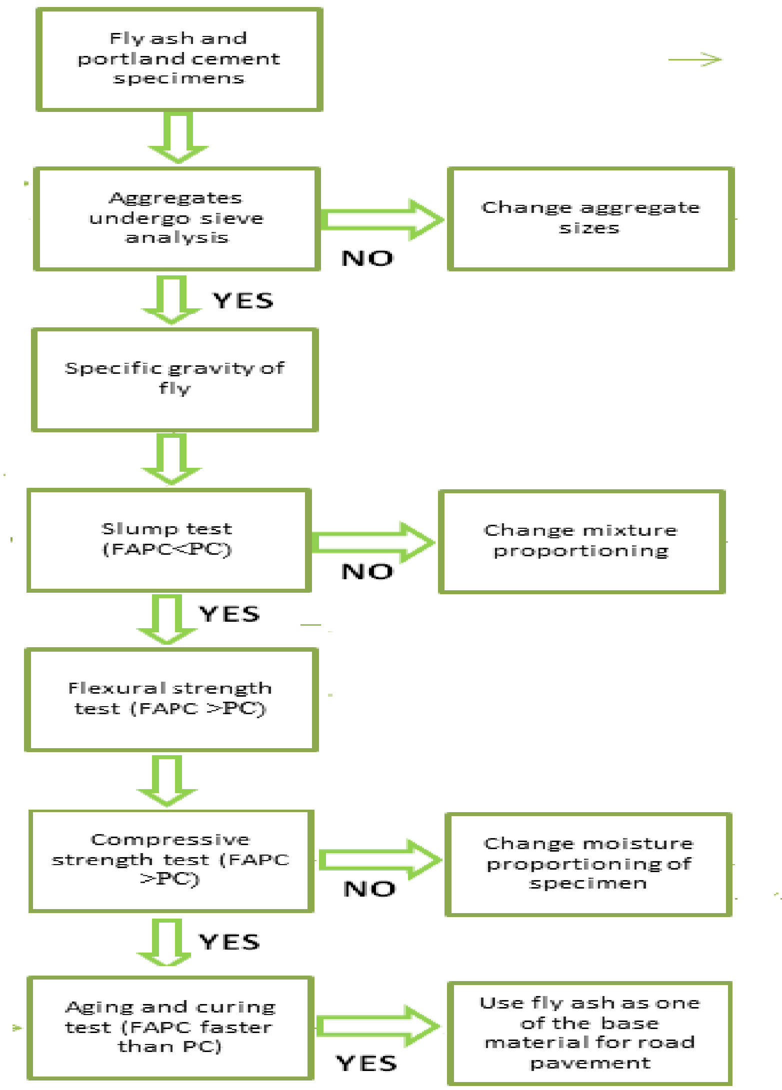

Figure 2. Project Development

3. Results and Discussion

3.1. Components of Plain Concrete and Fly Ash Cement Concrete

The physical and chemical properties of materials used in this study are listed in Table 1. The fly ash was characterized as a fine, powdery particle which has a high lime (CaO) content that helps act as a binder to hold the aggregates parts together. The sand was observed as a porous rock consisting grain of sand that has available size used in construction with the sieve analysis of 150um, 600um and 1.18um. This implied color to cementitious substance. In the gravel, there is a small pebble rock fragment that has a size of 9.5mm, 12.5mm and 19mm which is made of crystalline silica whereas cement was characterized as grayish powder made of limestone.

Table 1. Physical and Chemical Properties of Materials Used

Materials	Physical property	Chemical property
Fly ash	Powdery particles- fine particles, spherical in shape, either solid or hollow and mostly glassy in nature	Calcium hydroxide, calcium sulfate, and glassy components in combination with alumina and silica
Sand	Porous rock- consisting grains of sand or fine aggregate it has an available size of 150um(sieve no.160), 300um(sieve no. 50), 600um(sieve no. 30) and 1.18mm(sieve no.16)	Clay and silica – it gives characteristic colors for cementitious substance
Gravel	Small pebbles of rock fragments has coarser than sand have an available size of 3/8"(9.5mm), ½"(12.5mm), ¾"(19.0mm)and 1"(2.50mm)	Crystalline silica
Cement	Grayish powder	Limestone or chalk Clay or shale- it characterized as paste component

The mix proportion of specimens is shown in Table 2. The proportion used is 1:2:4 specified for concrete pavement. Volume of each raw material is taken per cubic meter of concrete mixture.

Table 2. Mix Proportion of Specimens

Raw Materials	Volume per cubic meter of concrete mixture	
	Plain Cement Concrete	Fly Ash Cement Concrete
Cement	0.14 m^3	0.1 m^3
Sand	0.29 m^3	0.29 m^3
Gravel	0.57 m^3	0.57 m^3
Fly Ash	-	0.04 m^3
Total Volume	**1.0 m^3**	**1.0 m^3**

The mix proportion of plain cement concrete specimen is shown in Figure 3. The proportion used is 1:2:4 specified for concrete pavement. The pie chart represents one cubic meter of plain cement concrete mixture divided into percentage of raw materials used. The specimens were formed in rectangular and cylindrical molds.

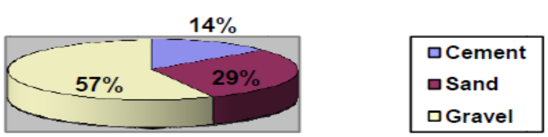

Figure 3. Mix Proportion of Plain Concrete Specimen

The actual weight and dimension of rectangular and cylindrical specimens used in this study are listed in Table 3 and Table 4 respectively. The specimen was cast in a rectangular mold approximately 154 mm. x 154 mm. x 460 mm. and in a cylindrical mold approximately with diameter of 154 mm. and height of 306 mm. Each specimen is weighed before testing in the universal testing machine.

Table 3. Actual Weight and Dimension of the Rectangular Specimens

Days	Specimen	L (mm)	W (mm)	Th (mm)	Area (mm^2)	Weight (kg)
Plain Concrete						
7	A	460	156	140	21840	24.0
	B	460	153	140	21420	22.7
	C	458	154	136	20944	23.5
14	A	457	153	140	21420	22.6
	B	455	154	151	23254	23.0
	C	453	152	135	20520	22.0
Fly Ash-Cement Concrete						
7	A	460	160	127	20320	25.0
	B	460	153	126	19278	25.0
	C	458	160	119	19040	24.2
14	A	458	151	152	22952	22.6
	B	458	153	135	20655	22.4
	C	460	154	148	22792	24.8

Table 4. Actual Weight and Dimension of the Cylindrical Specimens

Days	Specimen	H (mm)	Dia. (mm)	Area (mm^2)	Weight (kg)
Plain Concrete					
7	A	305	152	18241.5	13.4
	B	307	155	18869.2	13.2
14	A	303	155	18869.2	14.0
	B	309	150	17671.5	13.0
Fly Ash-Cement Concrete					
7	A	310	155	18869.2	15.5
	B	306	152	18145.8	13.4
14	A	308	154	18626.5	14.2
	B	308	156	19113.5	14.6

3.2. Mechanical Properties of Plain Concrete and Fly Ash Cement Concrete

The specific gravity test results of fly ash using a pycnometer is given in Table 5. This shows that the specific gravity of fly ash is lesser than the commercial cement.

Table 5. Specific Gravity Test Results of Fly Ash

Number of trials	1	2	3
Weight of pycnometer + water (g) Wa	65.3	66.1	66.3
Weight of pycnometer + water + fly ash (g) Wb	69.4	70.0	70.5
Weight of dry fly ash (g) Wo	10	10	10
Specific Gravity, $\frac{Wo}{Wo + (Wa - Wb)}$	1.69	1.64	1.72
Average Specific Gravity	1.68		

The comparative specific gravity result of cement and fly ash is shown in Figure 4. The specific gravity of fly ash is lower than that of cement. Specific gravity is 3 while fly ash is 1.68.

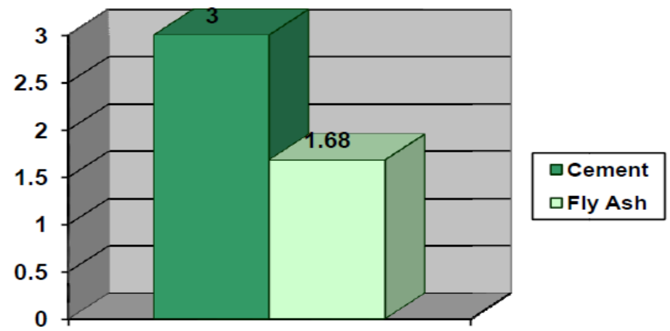

Figure 4. Comparative Specific Gravity Test Results of Plain Cement and Fly Ash Cement Concrete

As shown in Figure 5, the slump test result of plain cement concrete and fly ash cement concrete. The consistency of mixture is tested by the slump test. By comparing the results it can be seen that concrete with 30% fly ash settles at a large amount than the plain concrete.

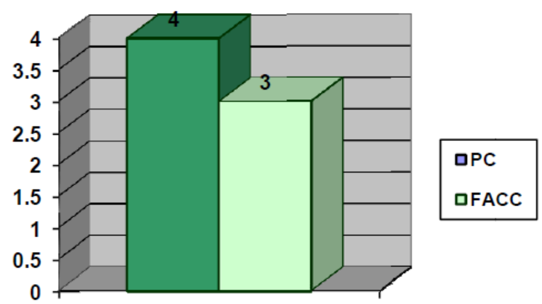

Figure 5. Comparative Slump Test Results of Plain Cement and Fly Ash Cement Concrete

The flexural strength of specimen is shown in Table 6. The flexural strength result of fly ash-cement concrete specimen is higher than the plain cement concrete. At the first testing, 7 days of curing, the fly ash cement concrete achieved twice the strength of the plain cement concrete. And until the last testing, 14 days of curing, still the fly ash-cement concrete more than twice the strength of the plain cement concrete.

Table 6. Flexural Strength Test Result of Rectangular Specimens

	Plain Concrete		Fly Ash Cement Concrete	
Time (days)	**Ultimate Load Capacity (KN)**	**Ultimate Strength (MPa)**	**Ultimate Load Capacity (KN)**	**Ultimate Strength (MPa)**
7	3.88	0.18	4.50	0.22
	8.08	0.38	6.81	0.32
	8.66	0.41	4.16	0.22
14	8.21	0.38	8.41	0.37
	10.33	0.44	11.51	0.56
	8.57	0.42	10.7	0.47

Table 7. Compressive Strength Test Result of Cylindrical Specimens

	Plain Concrete		Fly Ash Cement Concrete	
Time (days)	Ultimate Load Capacity (KN)	Ultimate Strength (MPa)	Ultimate Load Capacity (KN)	Ultimate Strength (MPa)
7	3.88	0.18	4.50	0.22
	8.08	0.38	6.81	0.32
	8.66	0.41	4.16	0.22
14	8.21	0.38	8.41	0.37
	10.33	0.44	11.51	0.56
	8.57	0.42	10.7	0.47

The flexural and compressive strength versus the curing period diagram is shown in Figures 6 and 7, respectively. By comparing the results between plain concrete and fly-ash cement concrete specimen, it can be found that the strength of fly-ash cement concrete develops at a faster rate than the plain cement concrete specimen within 7 days. Fly ash increases the rate of curing of the concrete mixture. Fly ash chemically reacts with lime produced by the hydration of cement and water, thereby closing off their voids that allow the movement of moisture through the concrete.

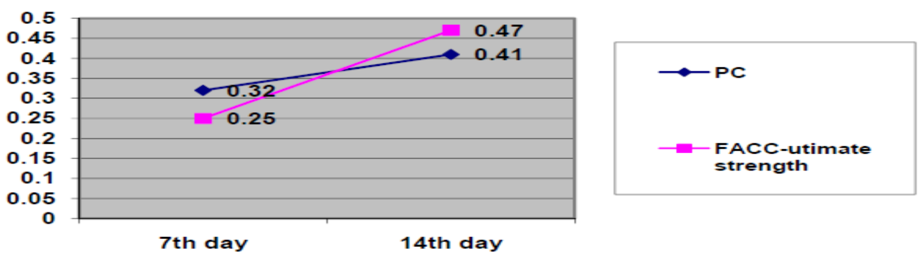

Figure 6. Comparative Flexural Strength Test Results of Plain Concrete and Fly Ash Cement Concrete

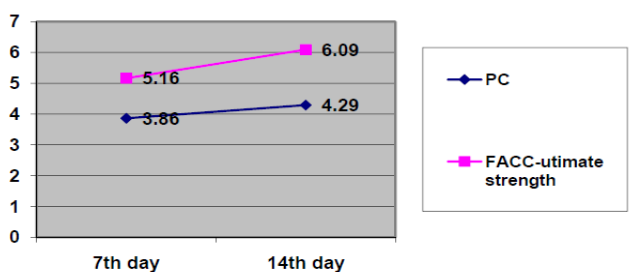

Figure 7. Comparative Compressive Strength Test Results of Plain Concrete and Fly Ash Cement Concrete

3.3. Effect of Fly Ash

3.3.1. Specific Gravity: Fly ash has a lower unit weight, which means that on a gram per gram basis, fly ash contributes roughly more percent volume of cementitious material per gram versus cement. The greater the percentage of fly ash in the paste, the better lubricated the aggregates are and the better the concrete flows.

3.3.2. Consistency: Fly ash reduces the amount of water needed to produce a given slump. The spherical shape of the fly ash particles and its dispersive ability provide water reducing characteristics.

3.3.3. Flexural Strength: Fly ash continues to combine with the lime in cement, increasing flexural strength over time. It helps the concrete mixture achieve its maximum strength faster.

3.3.4. Compressive Strength: Fly ash continues to combine with the lime in cement, increasing compressive strength over time. It helps the concrete mixture achieve its maximum strength faster.

3.3.5. Rate of Curing: Fly ash increases the rate of curing of the concrete mixture. Fly ash chemically reacts with lime produced by the hydration of cement and water, thereby closing off their voids that allow the movement of moisture through the concrete.

5. Conclusion

For a given set of materials in a concrete mixture, there may be a Portland cement content that produces a maximum concrete strength. In order to obtain higher strengths one of the most practical methods is the use of fly ash in the mixture. Fly ash proportioned using the concepts suggested by this paper has been shown to give strengths significantly above those obtainable by a Portland cement concrete. The method of proportioning proposed in this paper allows for the use of a wide range of fly ashes, it has been found that it is not the quality of fly ash that is important but the variation of that quality about a mean. Good concrete can be proportioned containing a low quality fly ash as long as that quality does not vary substantially. The greatest advantage of the use of fly ash in concrete is the flexibility that it allows with the selection of the mixture proportions. By use of the fly ash, a wide range of possible mixtures can be investigated for any specification. For each situation it is possible to choose either the lowest cost mixture, or the easiest to place, or the most durable. Fly ash has a lower unit weight which means the greater the percentage of fly ash in the paste, the better lubricated the aggregates are and the better the concrete flows and continues to combine with the lime in cement, increasing compressive strength over time. It helps the concrete mixture achieve its maximum strength faster. This shows that fly ash can be used effectively as material in concrete road pavement

6. Appendix

Figure 8. Fly Ash Cement Concrete

Figure 9. Testing of Specimen

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