Effect of Density and Porosity on the Durability of Flyash blended Concrete

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Abstract - *This study examines the role of cement and flyash & its concentration on the durability and porosity of fly ash blended concrete. The physical and chemical properties were investigated indicating different performances from each other. The advantage of Flyash blended concrete is to significantly reduced carbon footprint. In this study, Flyash concrete were prepared by mixing flyash at the proportion of 20%, 30%, 40% & 50% respectively and then investigated for porosity & durability. The results revealed that microstructural properties of fly ash particles, silica and calcium content have a significant effect on the porosity and the bonding of Fly ash concrete. The existence of capillary pores and air voids influences concrete permeability to a large extent. Concrete density is inversely proportional to its porosity. The entry of aggressive agents into the pore structure is responsible for various durability problems in concrete structures. Therefore, a durable concrete should have low permeability. Permeability of concrete increases with the increase in porosity of concrete. Various factors such as water to cementitious materials ratio, degree of hydration, air content, consolidation, mineral admixtures, aggregates, reaction between aggregate and cement paste, pozzolanic admixture, etc., affect concrete porosity. The effects of these factors on concrete porosity and durability are discussed in this paper.*

***Key Words*: Density, Porosity, Durability, Flyash Cement & Concrete.**

1. INTRODUCTION

Concrete density depends upon volume fractions of constituent materials and their densities, and the volume of voids present in the concrete. Concrete can be divided into two major phases at a macroscopic level. These are coarse aggregates and matrix which constitutes of mortar, hydrated cement paste and sand. Each of these phases is also a composite material. Out of the region between the aggregates (coarse or fine) and hydrated cement paste, former is more porous than the hcp and it can be considered as a third phase at a microscopic level. The aggregate phase is largely responsible for the unit weight and dimensional stability of concrete. These properties are dictated by bulk density and strength of the aggregate. The volume, size, and distribution of pores present in the aggregate control these properties to a large extent. In order to produce dense concrete, the porosity of the concrete should be less. Classification of aggregates is done according to size, bulk density, or source. The coarse aggregates are composed of particles greater than 4.75 mm, and fine aggregates contain particles of less than 4.75 mm. Based on bulk density, coarse aggregates are classified into three categories: normal weight aggregate (1520 to 1680 kg/m3), lightweight (1120 kg/m3), and heavyweight (above 2080 kg/m3).

Coarse aggregates are relatively more impermeable than the hydrated cement paste. The hydrated cement paste is composed of solids and voids. The major solids are crystals of calcium silicate hydrates (C-S-H), Calcium hydroxide (Ca (OH)2), calcium sulfoaluminates (C6AS3H32), and unhydrated portland cement clinker grain. The volume occupied by these crystals varies from 50 to 60% for C-S-H, 20 to 25% for Ca(OH)2, and 15 to 20% for calcium sulfoaluminates of total volumes of solids in a completely hydrated cement paste. The C-S-H crystals (C-S-H gel), being the major component of solids, play a great role in influencing concrete properties. The solid-to-solid distance between the C-S-H layer (gel pore) is found to vary between 5 to 25 A (1 A = 10-5 mm). Due to their size, these pores can influence drying shrinkage and creep behaviour of concrete.

Compared to C-S-H crystals, greater pore sizes are observed between the solid of Ca(OH)2 and calcium sulfoaluminate crystals. Capillary voids are created by water particles movements and the spaces which are not occupied by solid components are known to make a major contribution to porosity of the concrete. The size of capillary voids is much larger at the interfacial zone, the region at the interface of the aggregate and the hydrated cement paste compared to the bulk cement paste. The size of capillary voids can range from 10 to 50 nm (1 nm = 10-6 mm) in low water to cementitious materials ratio pastes while for high water to cementitious materials ratio paste. Capillary pores are relatively larger up to 3 to 5 µm. Additional concrete porosity results from entrapped air voids. Entrapped air voids are as large as 3 mm and larger in size as compared to entrained air which ranges from 50 to 200 µm, (1 µm = 0.001 mm). Both capillary voids and air voids influences the concrete permeability, durability and strength. The voids/flaws present in the concrete reduces the mechanical strength of the concrete due to the stress concentration effects. Thus, porosity of concrete composed of large pores has detrimental effects on both permeability and strength of the concrete.

Concrete durability is a related property and have negative effect due to expansions that result from factors such as freezing and thawing, alkali-aggregate reactions, sulphate attack, corrosion of the reinforcement, etc. Such expansions depend to a large extent upon entry of water, gases, and aggressive chemicals into the concrete which in turn, depend upon permeability and porosity. Therefore, porosity of concrete can be used as a measure of concrete durability. Porosity effects can be related to concrete durability. For given constituent materials, the porosity of the hydrated cement paste depends upon several factors such as water to cementitious materials ratio, Degree of hydration, Air content, Consolidation, Admixtures, Aggregates and reaction between aggregate and cement paste.

For a given cementitious material content of a concrete mixture, the space occupied by the hydration product increases with increasing water content. However, the volume of the hydration product will remain constant irrespective of the water content of the mixture at a particular degree of hydration. Therefore the unfilled spaces, gel pores and capillary voids in cementitious materials will cause an increase in porosity and a decrease in density of concrete.

In a freshly mixed concrete, water films are formed around the aggregate. As a result, a higher water to cementitious materials ratio is present in the interface region compared to the bulk cement paste. This condition also favours formation of larger crystals of calcium hydroxide and ettringite. This results in a higher porosity and lower density in the interface region relative to the bulk cement paste. The degree of hydration increases with age. Both gel pores and capillary pores volume and pore size decrease with an increase in the degree of hydration due to the formation of increased amounts of hydration products. This leads to improved microstructure conditions. A combination of relative humidity, time, and temperature should be selected so as to obtain denser microstructure and to avoid micro cracking of concrete.

Compaction of freshly mixed concrete allows elimination of entrapped air pockets and placement of concrete at a low water to cementitious materials ratio. Compaction/consolidation also decreases capillary pores. Consequently, proper compaction causes reduction in porosity and increase in density. This effect is more pronounced in the interface region where packing of cement particles is inefficient. Inclusion of reactive pozzolanic additives such as fly ash, slag, silica fume, natural pozzolans and rice husk ash improves concrete microstructure. This happens due to the densification of the microstructure that occurs as a result of the production of pozzolanic C-S-H. The use of pozzolanic additives is essential for densification of the interface region, in production of high-strength and/or high-performance concretes. This causes reduction in the amount and size of gel and capillary pores. As a result, a denser concrete microstructure is produced, which in turn, improves concrete strength and permeability.

The size and shape of coarse aggregates can affect concrete microstructure to a large extent. In general, an increase in the maximum size of aggregate or amount of flat particles tends to increase the amount of water in the vicinity of the aggregate. As a result, the water distribution in the mortar matrix becomes non-uniform. This occurs due to bleeding and the wall effects around aggregates that prevent packing of cement grains of large size 10μm or more. Therefore, shape, size, and amount of flat aggregates permitted should be judiciously selected to avoid increase in porosity or decrease in density of concrete.

2. Effect of Mixture Proportioning

Reaction between Aggregate and Cement Paste chemical composition of the aggregate can influence the porosity of the interface region. When the aggregate reacts with the hydroxide complex occurs in the interface region. This can result in increased density and decreased porosity of the interfacial region of concrete. Chemical composition of the aggregate can influence the porosity of the interface region. The mixture proportioning plays a significant role in packing of cement particles near the interface region. In general, a low water to cementitious materials ratio and a high aggregate/cement ratio promotes packing of cement particles in the interfacial region. Improved packing results in decreased porosity of concrete and increased density of concrete. This means that a durable concrete will maintain its original form, quality, and serviceability when exposed to various environmental conditions. The movement of water or other fluids through concrete can carry aggressive agents which create various types of durability problems for concrete construction. In fact, permeability controls the rate at which aggressive agents such as gases (CO2, SO2, etc.) and liquids (acid rain, sea water, sulfate rich water, salt-bearing snow/water, groundwater, etc. can penetrate into concrete. Therefore, in order to avoid permeation of these agents, permeability of concrete must be reduced by decreasing porosity and/or increasing density of the concrete. Due to slow pozzolanic reaction of many fly ashes, a greater curing time is required for fly ash concrete compared to concrete without fly ash.

Due to relatively high porosity of the interfacial zone compared to other regions, it becomes a weak link in the concrete structure. As a result, concrete strength and durability-related properties are dictated by the properties of the interface region to a marked extent. In order to improve concrete durability, it is essential to improve strength and durability of the interfacial region. In general, attempts have been made to improve properties of the interfacial region through the use of mineral additives and chemical admixtures.

3. Test Results

Flyash is a residual material, composed of long chains and networks of inorganic molecules, that is used as an alternative to conventional portland cement for civil infrastructure applications.

Table 1. Physical Properties of Fly Ash Standards

		ASTM	
Category		Class C	Class F
Fineness	Amount retained on 45µm sieve (max %)	34	34
	Specific surface area (min cm2/g)	-	-
Density (g/cm3)		-	-
Water requirement (max %)		105	105
Flow value ratio (min %)		-	-
Strength activity index (min %)	28 days	75	75
	91 days	-	-
Autoclave expansion (max %)		0.8	0.8
Drying shrinkage (28 days, max %)		0.03	0.03
Reactivity with cement alkalies			
(Mortar expansion, 14 days, max %)		0.02	0.02

Table 2. Chemical Composition of Fly Ash Standards

	ASTM	
Category	C	F
S+A+F (min %)*	55	70
SiO2 (max %)	-	-
SO3 (max %)	5	5
Moisture (max %)	3	3
L. O. I. (max %)**	6	6

3.1 Fly Ash Replacement Ratio

The replacement ratio of the fly ash (% of cement weight) used in concrete must be determined based on a consideration of the structure and operating environment. As for economic feasibility, the highest replacement ratio that satisfied all the above conditions was chosen in order to use as much fly ash as possible, because fly ash is more economically efficient than cement.

This mix proportion was used to prepare the specimens in order to compare the performance of each type of concrete.

Test category	**Test conditions**	**Measurement Category**	**Measurement period**	**Specimen size**
Carbonation	CO2 concentration: 10% Temperature: 30ºC Humidity: 50%	Carbonation depth Carbonation coefficient	28 days	100mm x 100mm x100mm

3.2 Carbonation Resistance Test

The 100 x 100 x 100mm specimens were de-molded after one day and placed under standard curing for 28 days in water at 23ºC. Five sides were coated with epoxy to induce the carbon dioxide penetration in one direction. Since the carbonation of concrete is affected by the concentration of carbon dioxide, and by the temperature and humidity, the conditions in this acceleration were set at 10% carbon dioxide concentration, 30ºC temperature and 50% humidity. The specimens on the carbonation acceleration were split into two at days 7 and 28 days and then 1% phenolphthalein solution was sprayed and the carbonation depth was measured. Figs. 1 show the carbonation speed coefficient, converted from the measured carbonation depths. Here, the carbonation speed coefficient refers to the ratio of the carbonation depth and the square root of age.

The carbonation speed increases regardless of the strength and age. The carbonation speed of the fly ash mixed concrete increases because of the reduction in the cement amount due to the replacement by fly ash and due to the decrease in the pH of the pore solution of the hardened concrete, which results from the consumption of alkaline Ca(OH)2 by the pozzolanic reaction. In addition, the carbonation speed decreases as the strength and age increase, regardless of cement type, and this tendency is particularly noticeable in fly ash mixed concrete. When fly ash is used at low strength as Lean Concrete, the resulting compound is somewhat disadvantageous in terms of carbonation.

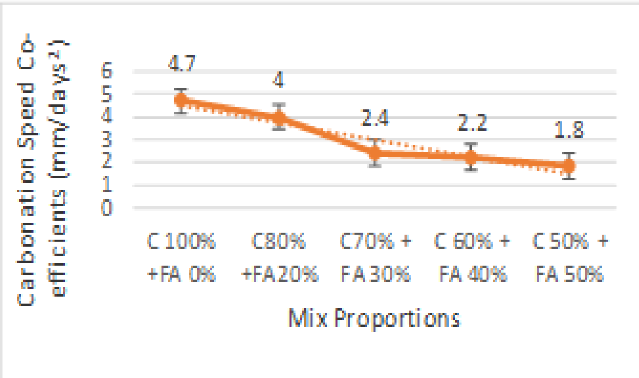

Fig.: 1 Carbonation Speed Co-efficient (28 days)

Therefore, it is judged that the dense micro structure of the fly ash mixed concrete acts as the main factor improving durability and properties.

4. CONCLUSIONS

Five mixtures of concrete specimens were investigated to evaluate the effect of 20%, 30, 40% & and 50% Fly ash content on some durability properties of concretes until 28 days of age. The following conclusions are drawn from the test results:

Incorporation of fly ash reduced the porosity of concrete in early age and it decreased further also. Concrete porosity is inversely proportional to its density. Concrete porosity is affected by a number of parameters, including water to cementitious materials ratio, degree of hydration, air content, consolidation, admixtures, aggregates, reaction between aggregate and the hydrated cement paste, mixture proportioning, etc. Of these, the water to cementitious materials ratio and degrees of hydration (curing) are the most important parameters that affect concrete porosity and thus concrete density. An increase in water to cementitious materials ratio increases porosity. For production of low porosity in concrete, a low water to cementitious materials ratio with optimum curing is used. An increase in compaction reduces porosity. The size of the interfacial region in concrete. The amount of flat aggregate should be minimized/avoided because it contributes significantly to the amount of weaker interfacial region. The introduction of pozzolanic additives, such as fly ash, natural pozzolans, slags, rice husk ash, and silica fume, cause refinement of grain and pore structures, especially in the interfacial region. Concrete permeability increases with an increase in porosity and decrease with an increase in density. For achieving high durability, concrete porosity should be kept low so as to reduce its permeability. A very high impermeable concrete will reduce or eliminate ingress of water and other aggressive chemicals and gases. This will lead to improved concrete durability due to avoided expansive reaction that can occur in presence of these aggressive agents. The theoretical and empirical models can be used to evaluate the effects of porosity on concrete strength properties.

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