Carbonation Depth Analysis of Concrete Using Various Fly Ash and Silica Fume Doses

Maninder Pal Singh
Assiatant Professor,
Department of Civil Engineering,
Guru Nanak Dev University,
Amritsar, Punjab.

Vishal Mahajan
Research Scholar,
Department of Civil Engineering,
Guru Nanak Dev University,
Amritsar, Punjab.

Abstract:- As part of a research initiative conducted by the governments of several nations, it has been noted that structures constructed between 1960 and 2000 are currently exhibiting significant indicators of degradation. It is clear that a harsh environment has an effect on failure rates. This paper reports on an experimental study that was conducted to examine how carbonation affected the mechanical characteristics of both plain concrete and concrete that had various doses of fly ash and silica fume added by weight replacement of ordinary Portland cement. This study uses cement with a constant water/cement ratio of 0.46. The effect of carbonation is observed by measuring the depth of carbonation using phenolphthalein solution. In the present study, it adjudged that from all fly ash and silica fume based mix combinations the mix combination PC20SF mentioned as the most optimum mix combination in terms of decrease in carbonation depth.

Keywords:- *Carbonation Depth, Durability of Concrete, Silica Fume, Fly Ash.*

I. INTRODUCTION

The corrosion of reinforcement, which leads to the deterioration of the structure, is commonly attributed to carbonation, one of the most important issues with reinforced concrete buildings. The pH of concrete pore solution drops from 12.6 to less than 9 due to carbonation, which is the reaction of the hydration products dissolved in the water with the carbon dioxide in the air. The theoretical carbonation process is very simple but in real is too much complex and is very important factor affecting concrete durability. Carbonation is a chemical reaction between calcium hydroxide and carbon dioxide which results in production of calcium carbonate. $Ca(OH)_2$ is a hydration result of bond, a rich measure of it creates an exceptionally basic condition in permeable arrangement. Carbonation-induced corrosion can increase crack development and decrease concrete durability. Carbonation reduces pH value and destroys the passive film around the steel, but it seems to density concrete surface and reduce chloride ion permeability, reduce surface porosity and hence sorptivity in concrete. The durability of concrete may be impacted by carbonation in both optimistic and pessimistic customs. The corrosion rate caused by carbonation of concrete is increased when even a modest amount of chloride is present. The diffusivity of the hardened cement paste is the primary factor affecting carbonation. The pace of carbonation is regulated by the diffusion of carbon dioxide into the concrete pore system, with a gradient in carbon dioxide concentration serving as the driving force. The type and quantity of cement, the material’s porosity, the curing time, and the kind and percentage of pozzolanic dosages are all factors that impact diffusion rate. Carbonation may alter concrete's mechanical characteristics, including its compressive strength, surface hardness, and resistance to aggressive chemicals.

II. EXPERIMENTAL PROGRAM

A. Materials Used and their Properties

The materials and their properties used in this study are presented in Table 1, 2 and 3.

Table 1 Properties of Odinary Portland Cement (OPC)

S. No	Characteristics	Results Obtained	Standard Results
1.	Normal Consistency	35%	-
2.	Initial Setting Time (minutes)	90 min.	Not less than 30
3.	Final Setting Time (minutes)	260 min.	Not greater than 600
4.	Blaines Fineness (%)	0.35 m^2/gm	<10
5.	Specific Gravity	3.06	-

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Table 2 Properties of Coarse Aggregates

S. No.	Characteristics	Results
1.	Type	Crushed
2.	Maximum Size	20mm
3.	Specific Gravity (10mm)	2.69
4.	Specific Gravity (20mm)	2.8
5.	Total Water Absorption (10mm)	1.59%
6.	Total Water Absorption (20mm)	3.64%
7.	Fineness Modulus (10mm)	6.46
8.	Fineness Modulus (20mm)	7.68

Table 3 Properties of Fine Aggregates

S. No.	Characteristics	Results
1.	Type	Uncrushed (natural)
2.	Specific Gravity	2.65
3.	Total Water Absorption	1.07%
4.	Fineness Modulus	2.507
5.	Grading Zone	III

B. Mixing and Preparation of Specimens

The proportion of concrete for one cubic meter is presented in table 4, the water cement ratio constant as 0.46 with a minimum cement content of 300 kg/m^3 is used. The different doses by weight replacement of fly ash and silica fume as mentioned in table 5 and table 6.

Table 4 Mix Proportions of Concrete (M20, Kg/m^3)

W/C Ratio	Water (Lt)	Plasticizer (Kg)	Ordinary Portland Cement (Kg)	Fine Aggregate (Kg)	Coarse Aggregate (Kg)
0.46	138	2.40	300	660	1330

The measurement of depth of carbonation for 14 and 28 days was focused in this study. Total of 27 cubes were casted and tested shown in figure 1. The specimens of concrete cubes were stored in a natural carbonation chamber. After extracting the specimens from the water tank, these set aside at room temperature for one day. Four cubes from per mix of dimension 50 mm×50 mm ×100 mm were split from each 150 mm×150 mm ×150 mm cubes at the age 28 days with the help of core cutter.

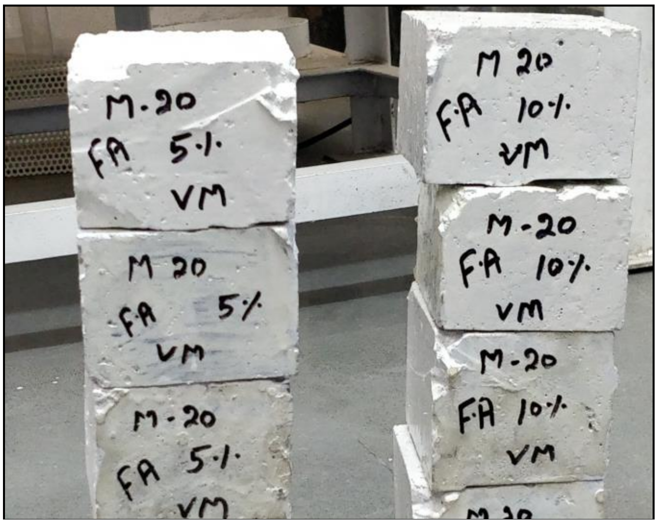

Fig. 1. Specimen Prepared after Cutting and Coated with Epoxy.

A unique code number assigned to every mix for understanding. The plain concrete was denoted as PC similarly FA stands for fly ash mixes and SF referred for mixes containing silica fume. The numerical values like 5, 10, 15 and 20 were the by weight replacement of %age of FA and SF to the cement as shown in table 5 and 6.

Table 5 Mix Combination with Fly Ash

S No	Mix Combination		
1.	Fly Ash % age	0%	PC
2.		5%	PC5FA
3.		10%	PC10FA
4.		15%	PC15FA
5.		20%	PC20FA

Table 6 Mix Combination with Silica Fume

S No	Mix Combination		
1.	Silica Fume % age	0%	OPC
2.		5%	OPC5SF
3.		10%	OPC10SF
4.		15%	OPC15SF
5.		20%	OPC20SF

C. Accelerated Carbonation

A Controlled Carbonation Chamber was used for carrying the experimental work, Figure 2. The concrete cubes were placed into the carbonation chamber and were dried to different RH of 40 and 60% and temperature of 27˚C to attain a constant mass. The mass loss of prisms was measured for each binder fraction. After the constant mass has achieved, four sides of cubes are coated with epoxy to allow ingress of CO_2 from only two sides.

Fig. 2. Specimens in Carbonation Chamber.

CO_2 have simultaneously injected into the carbonation chamber at 5% concentration. The concrete specimens were expected to carbonate approximately within 28 days. Thereafter the samples were tested for carbonation. From the two different relative humidity points it has expected that the carbonation should occur on one of them.

The penetration of carbonation was measured by cutting the specimens from the uncoated surface transversely and the exposed sections which have been cleared of dust and loose particles are sprayed with a liquid of 1% phenolphthalein in 70% ethyl alcohol. In the un-carbonated part of the specimen, where concrete was still highly basic, a purple-pink color was obtained. In the carbonated part, where the basicity of concrete was reduced, no coloration occurs. Immediately, the carbonation depths in these sections were measured by using a Vernier caliper as shown in figure 3. Each part was divided into six equal sections, and carbonation penetrations were observed at five spots in each of these sections. The depth of carbonation was rough; the average of these values was considered the overall carbonation depth for the given concrete prism.

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Fig. 3. Measurement of Carbonation Depth.

III. RESULTS AND DISCUSSION

A. Depth of Carbonation fro fly ash

It is evident from the table 7 and figure 4, that the depth of carbonation decreases around 21% with the curing period 14 days to 28 days; this is the effect of gaining the strength by concrete. For comprehensible understanding only 28 days curing period results were discussed here.

Table 7 Carbonation Depth for Fly Ash based Mixes

S No	Mix Combination			Carbonation Depth (mm)	
				14 days	28 days
1.	Fly Ash % age	0%	PC	18.7	14.85
2.		5%	PC5FA	15.8	12.9
3.		10%	PC10FA	13.4	11.4
4.		15%	PC15FA	11.7	8.8
5.		20%	PC20FA	10.9	8.3

Mixes containing fly ash PC5FA has the drop in depth of carbonation was 13% as compared to PC mix. Similarly, 23% decrease in PC10FA, 41% slump in PC15FA and 45% descend in the rate was observed in mix combination PC20FA as compared to PC mix combination. As compared to plain concrete and fly ash based concrete mix combinations at varying percentages showed decreased carbonation depth which is mainly due to the lowered concentration of calcium hydroxide.

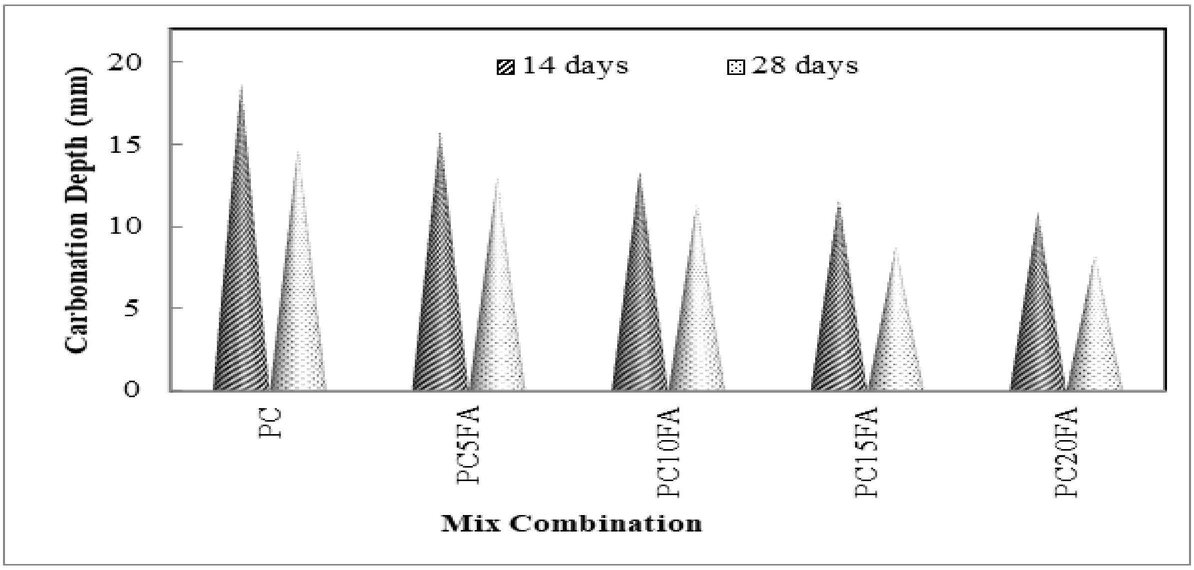

Fig. 4. Carbonation depth variation with different percentages of Fly Ash.

There is a dual consumption of $Ca(OH)_2$, first consumption due to pozzolanic reaction and the second due to carbonation reaction. The consumption of calcium hydroxide leads to reduction in alkalinity which is further measured as increased carbonation depth in plain concrete mix.

B. Depth of Carbonation for silica fume

It can also be seen from table 8 and figure 5 that with an increasing exposure period from 14 to 28 days, at all silica fume replacement, 5%, 10%, 15%, and 20%, the carbonation depth of concrete specimen strongly decreases. It was noticed decreases by 27% in PC5SF mix combination as compared to plain concrete mix. Alike decline was observed in carbonation depth by 40% in case of PC10SF mix combination as compared to PC mix combination. There was around 51% decrease in carbonation depth was observed in PC15SF mix combination compared to with PC mix combination. The most descended value by 57% found in case of mix combination PC20SF at 28 day of curing with contrast to the plain concrete mix.

Table 8 Carbonation Depth for Silica Fume based Mixes

S No	Mix Combination			Carbonation Depth (mm)	
				14 days	28 days
1.	Silica Fume % age	0%	PC	18.7	14.85
2.		5%	PC5SF	13.6	10.7
3.		10%	PC10SF	11.5	8.8
4.		15%	PC15SF	9.1	7.3
5.		20%	PC20SF	8.4	6.6

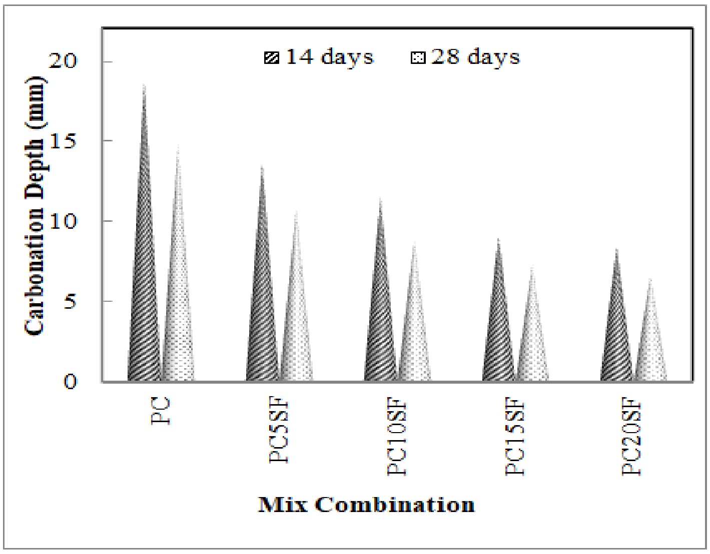

Fig. 5. Carbonation Depth Variation with Different Percentages of Silica Fume.

As the carbonation depth is proportional to exposure time therefore with decreasing carbon dioxide exposure period from 14 to 28 days, the carbonation depth decreases rigorously in all fly ash and silica fume replacement mix combinations. The fly ash and silica fume concrete mix combinations has increase strength, decreased porosity, and carbonation depth as compared to plain concrete mix due to its pozzolanic properties of fly ash and silica fume, which leads to a wrapping up that stronger concrete shows lower carbonation depth because of the decreased permeability.

IV. CONCLUSIONS

Between the environments of 40% and 60% RH, carbonation occurs only in 60% RH due to the availability of CO_2 to the dissolved calcium hydroxide. Whereas in the environment had 40% RH the pores were too dry, such that there is insufficient dissolved calcium hydroxide available for carbonation. Therefore, 60% RH is considered the critical moisture content for fly ash and silica fume concrete mix combinations. With an increasing percentage of fly ash and silica fume, carbonation depth sharply decreases at 14 and 28 days of exposure to CO_2 respectively for both plain concrete mixes because of the double utilisation of calcium hydroxide. This is first due to pozzolana reaction and the second due to carbonation reaction. With an increasing exposure period to CO_2 from 14 to 28 days carbonation depth decreases due to the directly proportional relationship between carbonation depth and exposure time.

The plain concrete mix while compared to of fly ash and silica fume concrete mix combinations shows reduced carbonation depth because of refined porous structure. Accelerated carbonation rate decreases with increasing fly ash and silica fume replacement in different doses.

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The most optimum fly ash based mix combination was PC20FA in terms of carbonation depth. Similarly the mix PC20SF found to be the most optimum mix combination containing silica fume.

It is adjudged that from all fly ash and silica fume based mix combinations the mix combination PC20SF mentioned as the most optimum mix combination in terms of decrease in carbonation depth.

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