Examine the Carbonation Depth of Concrete Containing Basalt Fibers and Fly Ash

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Abstract
According to a study undertaken by the governments of various countries, buildings built between 1961 and 2000 are now showing notable signs of deterioration. It's clear how an aggressive workplace affects the likelihood of failure. Given the concerns regarding the durability of concrete, this study aims to determine how carbonation affects the concrete's characteristics. This investigation was conducted on an experimental examination to examine carbonation's effects on the mechanical characteristics of ordinary Portland cement (OPC) and concrete that contained varying amounts of fly ash and basalt fibers by weight replacement. OPC with a constant water/cement ratio of 0.46 is used in this study. Depth of carbonation using phenolphthalein solution is measured to observe the effect of carbonation. The present study adjudged that from all basalt fibers and fly ash-based mix combinations the mix combination MB5F20 was adjudged as the most optimum mix combination in terms of increasing compressive strength, split tensile strength, and decrease in carbonation depth.

Keywords: Compressive strength, Tensile strength, Basalt fibers, Basalt fiber reinforced concrete.

1. Introduction

One of the biggest issues with reinforced concrete buildings is carbonation, which is well known to have a major role in the corrosion of reinforcement, which ultimately leads to structural degradation. The process known as carbonation occurs when the carbon dioxide in the air reacts with the hydration products dissolved in the pore water, lowering the pH of the concrete pore solution from 12.6 to less than 9. It can also damage the steel passive oxide film and speed up uniform corrosion. Although the carbonation process is quite straightforward in theory, it is extremely complex in practice and has a significant impact on the durability of concrete. Calcium hydroxide and carbon dioxide undergo a chemical reaction called carbonation, which yields calcium carbonate. A high concentration of $Ca(OH)_2$, a hydration product of bonds, produces an unusually basic situation in a permeable arrangement. Corrosion brought on by carbonation can shorten the lifespan of concrete and accelerate crack formation. Although carbonation lowers pH and breaks down the passive coating surrounding steel, it also appears to densify the surface of concrete, decrease chloride ion permeability, surface porosity, and therefore concrete sorptivity. The durability of concrete may be impacted by carbonation in both positive and negative ways. According to Glass et al., the corrosion rate caused by carbonation of concrete is increased when even a tiny 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 CO_2 into the concrete pore system, with a gradient in CO_2 concentration serving as the driving force. The kind and quantity of cement, the material's porosity, the curing period, and the kind and amount of pozzolanic additives are some of the variables that impact diffusion rate. Furthermore, carbonation may alter a number of concrete's mechanical characteristics, including its compressive strength, surface hardness, and resistance to aggressive agents.

2. Experimental Programme

2.1. Materials Specifications

Ordinary Portland cement, fly ash, fine aggregates, coarse aggregates, portable water and basalt fibers are utilized for this experimental investigation. The mechanical properties of concrete mix are depending upon the each ingredients property of materials. The main objective is to develop strength is to create a strong strength property and find carbonation depth.

2.1.1. Cement

Cement used in the experimental work was Ordinary Portland Cement (Table 1).

Table 1: Physical properties of OPC

Standard consistency	35%
Initial setting time	55min
Final setting time	310 min
Specific gravity	2.90

2.1.2. Aggregates

Fine aggregates are the natural sand which is washed and sieved to remove the large particle and lumps in the sand. The sand passed through 4.75 mm IS sieve was used. Locally available crushed stone coarse aggregates of maximum size 12.5 mm were used throughout the investigation. The physical properties of the fine aggregates and coarse aggregates are listed below in table 2 and 3.

Table 2: Physical properties of fine aggregates

Fineness Modulus	2.53
Specific Gravity	2.65
Water Absorption (%)	1.3
Moisture Content (%)	0.48

Table 3: Physical properties of coarse aggregates

Fineness Modulus	6.55
Specific Gravity	2.70
Flakiness Index (%)	11
Water Absorption (%)	0.3
Moisture Content (%)	0.5

2.1.3. Water

Water is generally regards as suitable for concrete and safe to drink. Oil, acids and organic matter should not present in water. Basically water serves two purposes in concrete mix. First it creates Cement paste through a chemical reaction with cement, which keeps insert aggregates suspended until the paste solidifies. Second, it serves as lubricants in cement and fine aggregate combination.

2.1.4. Basalt fiber

The golden brown color of the basalt fiber utilized as an addition in this investigation is depicted in Figure 1. Basalt fiber is used in reinforced concrete referred as basalt fiber reinforced concrete (BFRC) to assist prevent cracks during the hardening process, minimize leaks, and give corrosion resistance. The fiber filaments typically had an average diameter of 13 microns and an average length of 6 mm.

Figure 1: Basalt Fibers

2.2. Casting Of Specimens

For measuring all the dimensions of concrete cubes (150 mm X 150 mm X 150 mm) and cylinders (100 mm dia, 200 mm long),) filled with three layers fully compacted concrete poured in the moulds as give in figure 2. After 24hours specimen are de-molded and placed in curing tank for 14th and 28th days. For compressive strength, carbonation test 63 cubes, and 42 cylinders for split tensile strength were casted.

Figure 2: Specimen casting

2.3. Mix Proportions

2.3.1. Mixing and preparation of specimens

Water cement ratio constant as 0.46 with a minimum cement content of 300 kg/m^3 is used as presented in table 4. In this study M 20 mix used for plain concrete.

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

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

A unique code number assigned to every mix for understanding. The plain concrete was denoted as "M" similarly "FA" stands for fly ash mixes and "BF" referred for mixes containing basalt fibers. The numerical values like 10, 20 and 30 were the by weight replacement of % age of FA and BF volume fraction added by 3% and 5% respectively to the cement for preparation of mixes as shown in table 5.

Table 5: Mix Combinations

S No	Basalt Fiber (BF) % Age	Fly Ash (FA) % Age	Mix Combination	Mix Combination Code
1.	0	0	Plain Mix	M
2.	3	10	Plain Mix+3% Basalt Fibres + 10 % Fly Ash	MB3F10
3.		20	Plain Mix+3% Basalt Fibres + 20 % Fly Ash	MB3F20
4.		30	Plain Mix+3% Basalt Fibres + 10 % Fly Ash	MB3F30
5.	5	10	Plain Mix+5% Basalt Fibres + 10 % Fly Ash	MB5F10
6.		20	Plain Mix+5% Basalt Fibres + 20 % Fly Ash	MB5F20
7.		30	Plain Mix+5% Basalt Fibres + 30 % Fly Ash	MB5F30

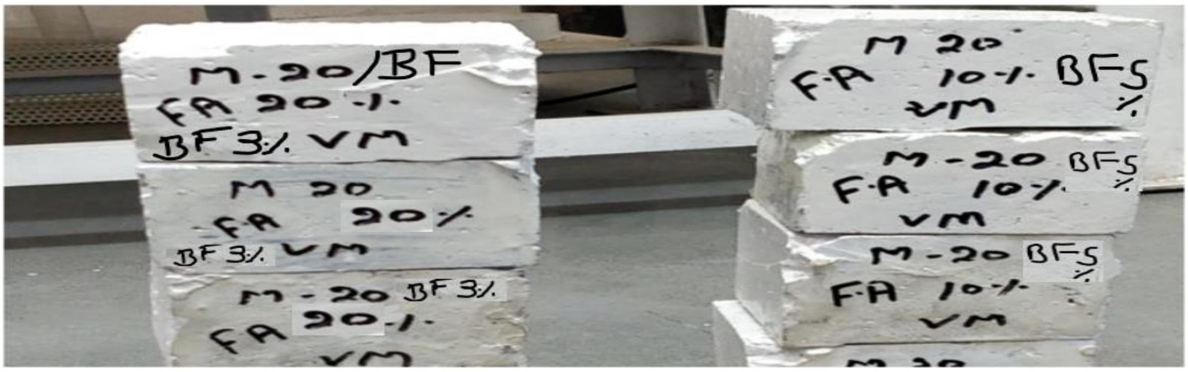

Figure 3: Specimen prepared after cutting and coated with epoxy.

In essence, measurement of depth of carbonation for 42th and 56th days was focused in this study. Based on which a total of 63 cubes and 42 cylinders were casted in order to have a better outcome. Cubes were casted keeping in view that each tests contain three cubes for testing so that an average value can be considered. These concrete cubes are 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 X 50 mm X100 mm were split from each 150 mm X 150 mm X150 mm cubes with the help of core cutter as shown in fig 3.

2.4. Accelerated Carbonation

A Controlled Carbonation Chamber was used for carrying the experimental work, Figure 4. 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. CO_2 have simultaneously injected into the carbonation chamber at 5% concentration. The concrete specimens were expected to carbonate approximately within 28 days from the date of get out from water curing. 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.

Figure 4: Specimens in carbonation chamber.

3. Results and Discussion

3.1. Compressive Strength Results

In table 6 results for compressive strength of all mixes at 14th days and 28th days have been presented. The main emphasis has been given to the results of 28th days for enhanced understanding. The plain mix combination shows the increase in compressive strength with curing age increased from 14th to 28th days as 22.8 and 26.83 MPa respectively. The increase in compressive strength observed in mix combinations MB3F10, MB3F20 and MB3F30 as 9%, 16% and 3% respectively. As the mix combinations containing MB5F10, MB5F20 and MB5F30 has the comparable trends of increased compressive strength like 22%, 31% and 5% respectively. It is clear from the results and fig 5 that on addition of BF and FA at different dosed the compressive strength increased. As the BF dose increased from 3% to 5% the compressive strength results has increased. As the dose of FA increased from 10% to 20% results has been increased significantly, however drop in compressive was observed on 30% addition of fly ash. The mix combination MB5F20 adjudge as optimum mix combination in terms of compressive strength.

Table 6: Compressive Strength Results

S No	Mix Combination	Compressive Strength (MPa)	
		14 Days	28 Days
1.	M	22.8	26.83
2.	MB3F10	25.44	29.14
3.	MB3F20	28.46	31.15
4.	MB3F30	24.31	27.54
5.	MB5F10	28.71	32.67
6.	MB5F20	31.24	35.18
7.	MB5F30	25.54	28.21

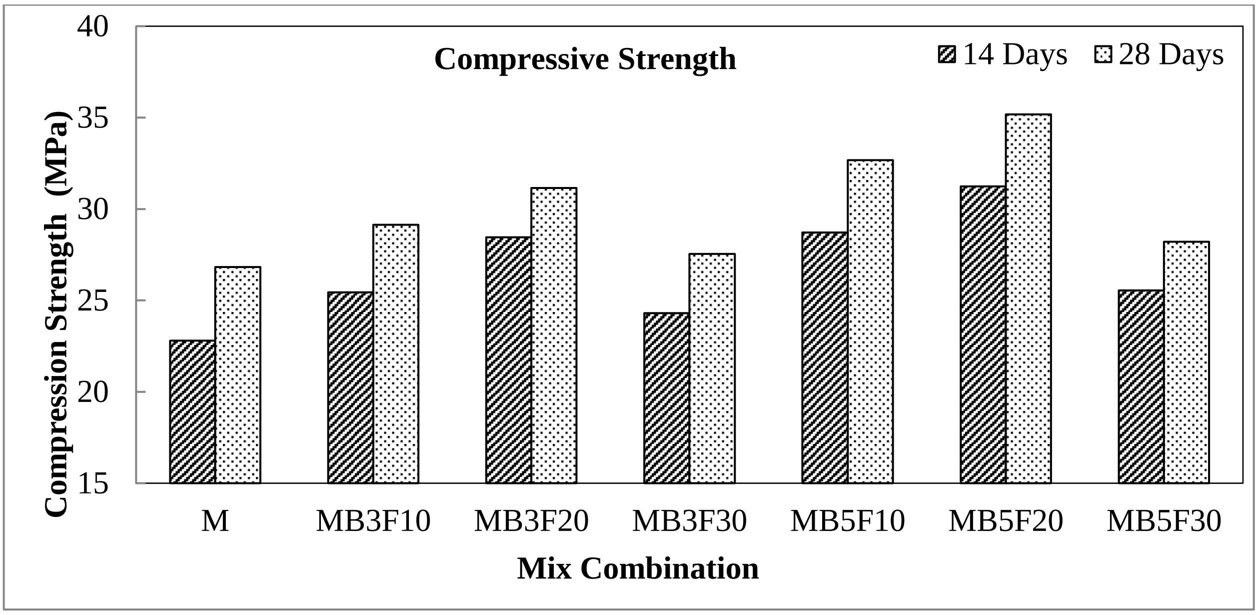

Figure 5: Compressive strength results of all mix combinations.

3.2. Split Tensile Strength results

The results for split tensile strength of all mixes at 14th days and 28th days have been presented in table 7. The plain mix combination shows the increase split tensile strength with curing age increased from 14th to 28th days as 2.81 and 3.07 MPa respectively. The increase in split tensile strength observed in mix combinations MB3F10, MB3F20 and MB3F30 as 25%, 50% and 9% respectively. As the mix combinations containing MB5F10, MB5F20 and MB5F30 has the alike trends of increased split tensile strength like 44%, 74% and 20% respectively. It is clear from the results and fig 6 that on addition of BF and FA at different dosed the split tensile strength increased. As the BF dose increased from 3% to 5% the split tensile strength results has increased. As the dose of FA increased from 10% to 20% results has been increased significantly, however drop in split tensile was observed on 30% addition of fly ash. The mix combination MB5F20 adjudge as optimum mix combination in terms of split tensile strength.

Table 7: Split Tensile Strength Results

S No	Mix Combination	Split Tensile Strength(MPa)	
		14 Days	28 Days
1.	M	2.81	3.07
2.	MB3F10	3.11	3.85
3.	MB3F20	4.19	4.61
4.	MB3F30	3.04	3.35
5.	MB5F10	4.15	4.42
6.	MB5F20	4.78	5.35
7.	MB5F30	3.22	3.67

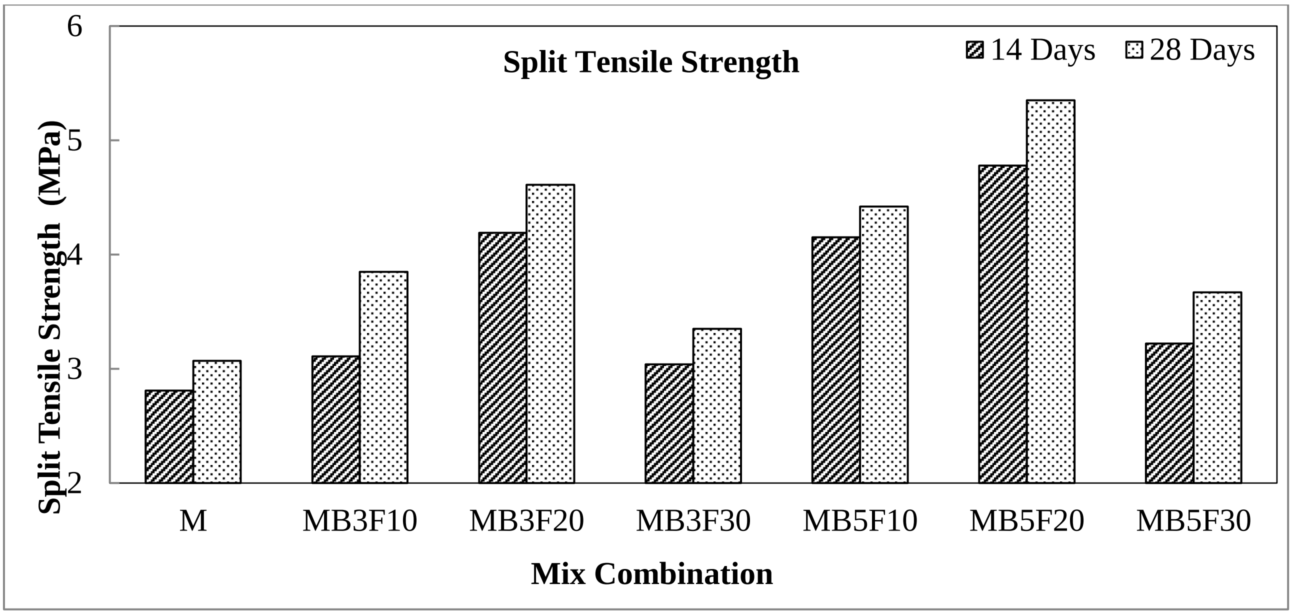

Figure 6: Split tensile strength results of all mix combinations.

3.3. Depth of Carbonation of Silica fume and fly ash

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 7. 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. In this study 14^{th} days curing specimens tested for carbonation test at 42^{th} days and 28^{th} day specimens at 56^{th} days respectively.

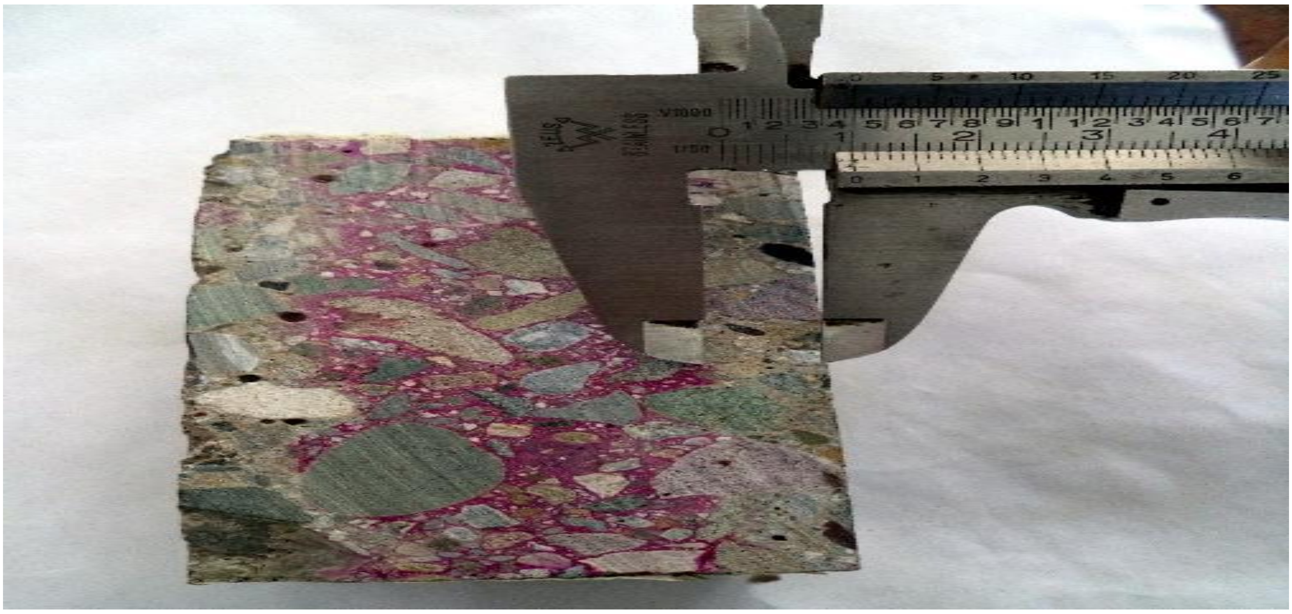

Figure 7: Measurement of carbonation depth.

Table 8: Carbonation Depth Results

S No	Mix Combination	Carbonation Depth (mm)	
		42 Days	56 Days
1.	M	22	20
2.	MB3F10	19	17
3.	MB3F20	15	12
4.	MB3F30	18	17
5.	MB5F10	14	11
6.	MB5F20	11	8
7.	MB5F30	17	16

It is evident from the table 8 and figure 8, that the depth of carbonation decreases around 9% with the curing period 14th days (Carbonation testing day 42th) to 28th days (carbonation testing day 56th day) in the case of plain concrete (PC); this is the effect of gaining the strength by concrete. For comprehensible understanding only 28th days curing period (Carbonation testing day 56th) results were discussed here.
Mixes containing different doses of fly ash and 3% BF, MB3F10 has the drop in depth of carbonation been 15% as compared to plain concrete mix. In the same way, 40% decrease in MB3F20 and 45% fall in MB3F30 was observed as compared to PC mix combination. In the similar trends observed in different doses of fly ash and 5% BF contain mixes. The mixes MB5F10 has the drop in depth of carbonation been 45% as compared to plain concrete mix. Also, 60% drastically decrease in MB5F20 and 20% fall in MB5F30 was observed 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. The most optimum in terms of carbonation depth results is adjudged MB5F20.

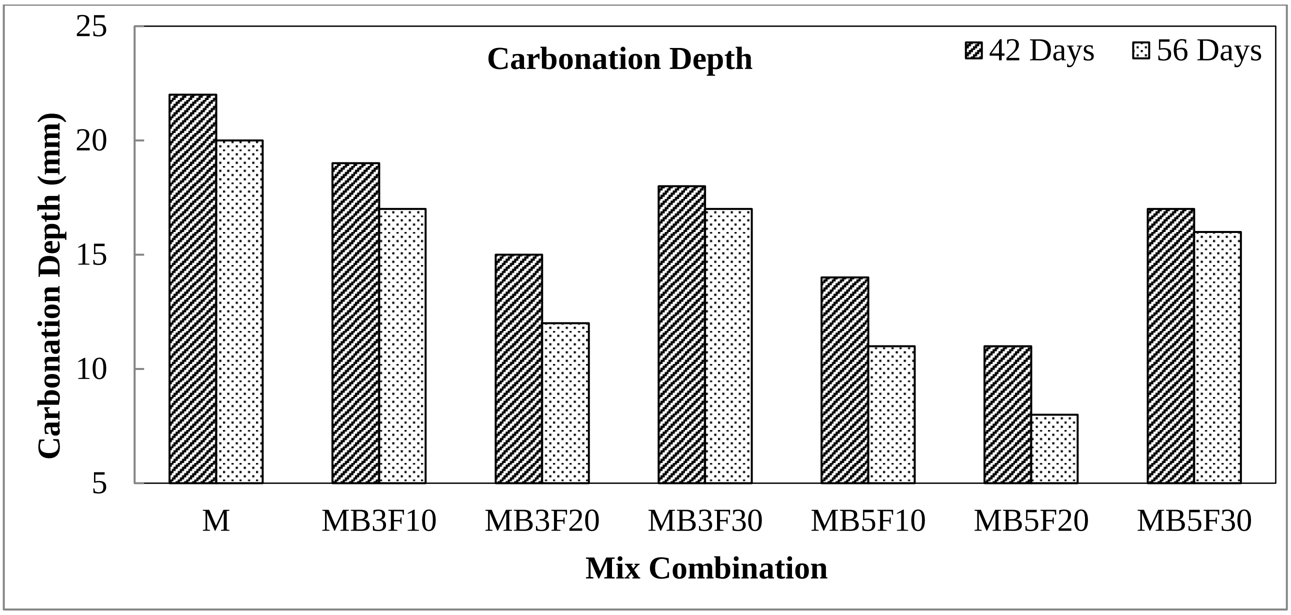

Figure 8: Carbonation depth results of all mix combinations at 42th and 56th days.

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.
As the carbonation depth is proportional to exposure time therefore with decreasing carbon dioxide exposure period from 14th to 28th days, the carbonation depth decreases rigorously in all fly ash and basalt fiber mix combinations. The fly ash and basalt fiber contained 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, which leads to a wrapping up that stronger concrete shows lower carbonation depth because of the decreased permeability.

4. CONCLUSIONS

Among 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 basalt fiber concrete mix combinations. With an increasing percentage of fly ash and basalt fiber, carbonation depth sharply decreases at 42th and 56th days of exposure to CO_2 respectively for both plain concrete mixes because of the double utilization 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 42th to 56th days the 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 basalt fiber 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.
It is adjudged that the most optimum mix combination containing fly ash and basalt fiber was MB5F20 in terms of compressive strength, split tensile strength and carbonation depth.

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