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Evaluation of Durability Index for Medium Strength Concrete

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Abstract— ***Durability of concrete can be defined as the ability of a structure to perform its intended function over a specified period of time under the influence of agents anticipated in service. It is considered as durable material and will retain its quality and serviceability in its original form when exposed to environment.***

In the design of reinforced concrete structures, the strength requirement is considered as mainly governing criterion. If cube strengths are OK, then concrete in the structure is fine, and it is considered that concrete will take care of itself. But reality is different. The aspect of the durability of the concrete was not given as much attention. Many structures have shown signs of deterioration earlier than expected for their service life, which has resulted in the need for repair and rehabilitation of these structures, often at great cost. This implies that the durability is related to the material performance and environment and cannot be thought of as being an inherent property of the concrete.

In present work, durability index for medium strength concrete containing M20, M40 and M50 with plain OPC and with replacement of OPC by fly ash by 30% are evaluated. Total 60 no. of cubes were casted, 10 for each type of mix. For durability index, three tests Oxygen Permeability, Water Sorptivity and Chloride Conductivity as per South African Durability Index Approach were carried out. From the Water Sorptivity and Chloride Conductivity results the concrete mixes were found to be of good category while found poor category from oxygen permeability.

Keywords — Concrete, Durability index, Oxygen permeability, Sorptivity, Chloride conductivity.

I. INTRODUCTION

Concrete is the most common material which is widely used for construction. It is composed mainly of cement, water, sand and aggregate. Often, supplementary materials are used in the form of mineral and chemical admixtures. It is expected that reinforced concrete structures should be maintenance-free during their service lives. However, there is evidence of premature deterioration of concrete structures.

Durability of concrete can be defined as the ability of a structure to perform its intended function over a specified period of time under the influence of agents anticipated in service. A concrete is considered durable if it performs satisfactorily in the working environment in expected exposure conditions during its service. Generally, in concrete mix design procedure only strength of concrete is considered. The belief that the strong concrete is a durable is not always true. In addition to strength of concrete another factors, such as environmental condition (exposure condition), transport mechanisms that involve the ingress of ions or molecules from surrounding liquids and gases into and through the materials are also important consideration for durability.

The durability of the concrete was not given as much attention. Consequently, many structures have shown signs of deterioration earlier than expected for their service life, which has resulted in the need for repair and rehabilitation of these structures, often at great cost. This imply that the durability is related to the material performance and environment and cannot be thought of as being an inherent property of the concrete. Thus, using strength as a guarantee of the concrete durability is not acceptable any longer.

II. LITERATURE REVIEW

[1] S.G. Cheriyan, B.S. Dhanya and Manu Santhanam 2014;

In this paper, authors tried to establish database for durability indices for common binder type in Indian condition using class C, class F fly ash and slag mixes and their combinations by replacement of cement. Water/cement ratio was kept limited to 0.5 with total binder content of 310 kg/m^3. Three tests as per South African Durability Index Manual 2010 (Oxygen Permeability Test, Water Sorptivity Test and Chloride Conductivity Test) and RCPT (as per ASTM C-1202), were carried out at 28th day and 90th day for durability indices.

It was concluded that, durability parameters improved with replacement of cement by mineral admixture. At an equivalent replacement level, Ternary blended systems perform better than binary binder systems. Concrete mixes using fly ash, shows much superior durability but significantly lower strength than the control mix, which indicates that, compressive strength and durability are not necessarily related, when mineral admixtures are used in concrete.

[2] Ekolu, S. O., & Murugan, 2012;

In this paper, To evaluate the influence of common cements on strength and durability of concrete, three durability index test methods were used. The concretes were classified as normal strength, medium strength and high strength concretes based on compressive strength result.
From the study, following conclusions were made:

Plain cement concretes showed higher sorptivity values compared to the cements containing extenders for the normal and medium strengths. Different cement types showed similar OPI values and similar sorptivity values for high strength concretes. Cement type has negligible influence on sorptivity and permeability for high-strength concretes. To achieve superior performance for high chloride resistance, incorporation of extenders may be required, as use of standard cements alone appears to be insufficient.

[3] F.T. Olorunsogo, N. Padayachee 2002;

From this research, authors made following conclusions:

Inclusion of RA decreased the permeability index of concrete mixes at a given curing age, whilst for a concrete mix containing a specific amount of RA; the index increased the longer the curing duration. For a given curing duration of concrete mixes, Chloride conductivity Index increases with increase in the replacement of Recycled Aggregate. However, at a particular replacement level of the RA, the longer the duration of curing, the lower the conductivity of a concrete mix. At a constant age of curing, water sorptivity of RA concrete increased with increases in the proportion of RA in the mixes. Sorptivity decreased the longer the curing age of concrete mixes for a given proportion of RA in the mix. Overall, durability quality of RA concrete reduced with increases in the quantities of RA that were included in a mix and, as expected, the quality improved with the age of curing. This phenomenon can be explained by the fact that cracks and fissures created in RA during processing render the aggregate susceptible to ease of permeation, diffusion and absorption of fluids.

[4] Suvash Chandra Paul and Gideon P.A.G. Van Zijl 2013;

In this research, the durability index performance of normal aggregate and 30% replacement of Recycled Concrete Aggregate (RCA) with it is described. No major difference in durability properties was found when 30% Recycled Concrete Aggregate was replaced to Natural Aggregate. For all three tests, a total four concrete disk samples of 28 ± 2 mm thickness and 70 ± 2 mm diameter were collected from each after this curing period. The samples were obtained by drilling into the exposed surface of 100 mm concrete cubes, and then by cutting the cylinders into the 28 mm slice. The samples were thereafter placed in an oven that was maintained at a temperature of 50 ± 20 ^{0}C and at a relative humidity of less than 20% for a minimum of 7 days ± 4 hrs. prior to testing.

For durability Index purpose, three tests namely, Oxygen permeability, Water sorptivity and Chloride Conductivity tests were performed. For all these three tests, procedures have been followed according to the University of Cape Town durability index testing procedure manual, 2009, version 1.

On the basis of the experimental tests carried out in this research, it is possible to conclude that for the same strength class of concrete Recycled Concrete Aggregate used in this study is of a high quality and there are no any significant differences in the mechanical behaviour and durability performance when compared with Natural Aggregate. Replacement of 30% shows higher sorptivity values. Replacement of 100% shows higher chloride conductivity. It has been shown that RCA30% has similar resistance to ingress by oxygen, water and chlorides. However, some sources of RCA can contain chloride, and should be a concern when such RCA is used in reinforced concrete.

III. EXPERIMENTAL METHODOLOGY

The experimental work was carried out systematically to achieve the required target. In this experimental program, Quantity calculation was carried out by preparing spreadsheets in Excel program. Mix design was carried out as per IS 10262:2009. Six different types of mix were prepared with and without fly ash content. 10 cubes were casted for each type of mix and hence total 60 no. of cubes of 150mm x 150mm x 150mm size were casted.

A. MATERIAL SPECIFICATIONS:

Cement: To prepare the samples, 53 grade ordinary Portland cement of Ultratech brand confirming to IS: 12269 – 1987 [III] was used. Specific gravity of cement was 3.1.

Fine Aggregates: Fine aggregate obtained from nearby river was used. Fine aggregate was of zone II by sieve analysis. Specific gravity of fine aggregate was 2.51.

Coarse aggregate: Coarse aggregates were used of 20mm maximum size. Specific gravity of coarse aggregate 2.8.

Water: As a constituent of matrix, simple tap water available in laboratory was used. Water quantity was taken with reference to cement content.

Fly Ash: Fly ash used for the present investigation was a processed siliceous pulverized ash confirming to IS 3812 (Part 1): 2003.

Super Plasticizer: For preparing mix with a lower w/c ratio, super plasticizer is needed for good workability of matrix. For this purpose, FAIRFLOW 101 super plasticizer manufactured by Fairmate pvt. Ltd. was used. Specific gravity of this super plasticizer was 1.07.

B. CONCRETE MIX DESIGN:

To produce a good matrix, materials should be taken in some proportion to each other. For present study, concrete mix design was carried out in accordance with IS 10262:2009. Normal curing was done at room temperature in the laboratory. For each mix 3 cubes were tested for compressive strength at 7 days and 3 cubes were tested at 28 days.

After curing period of 28 days, cores of 70mm ± 2mm dia. were extracted from cubes. And then specimens were prepared of 30 ± 2mm thickness by cutting the cores. After extracting the cores, the curved surface of the core was coated with epoxy.

Fig. 1 SPECIMEN FOR DURABILITY TESTS

For durability testing propose, three tests namely Oxygen Permeability test, Water Sorptivity test and Chloride Conductivity test were carried out as per South African Durability Index Testing Manual 2010. For each test 4 specimens were tested for each mix type.

IV. RESULT AND ANALYSIS

A. COMPRESSIVE STRENGTH TEST RESULTS:

For finding compressive strength of the specimens, 3 cubes at 7th day and 3 cubes at 28th day for each type of mix were tested. The results of compressive strength are summarized as follows.

From compressive strength, we can say that, Plain OPC mixes have higher compressive strength than the Fly Ash mixes at 7th day and 28th day.

B. DURABILITY INDEX TEST:

For finding Durability Index, three tests were performed namely oxygen permeability, water sorptivity and chloride conductivity as per South African Durability Index Manual 2010. The results obtained by the tests were compared with standard manual.

TABLE I: COMPRESSIVE STRENGTH RESULT

Mix No.	Mix Type	7th day Strength (N/mm^2)	Avg. 7th day Strength (N/mm^2)	28th day Strength (N/mm^2)	Avg. 28th day Strength (N/mm^2)
1	M20	21.33	20	29.33	30.07
		19.11		31.11	
		19.55		29.77	
2	M20 with FA	16	16.3	30.22	28.74
		15.55		30.22	
		17.33		25.77	
3	M40	21.77	22.81	42.67	42.22
		23.11		40.88	
		23.55		43.11	
4	M40 with FA	25.33	24.15	42.2	41.18
		24.44		42.67	
		22.67		38.67	
5	M50	34.67	35.85	54.32	53.99
		37.33		54.32	
		35.55		53.33	
6	M50 with FA	31.55	29.18	53.33	51.26
		30.22		49.77	
		25.77		50.67	

I. OXYGEN PERMEABILITY TEST:

For computing OPI, the pressure decay curve measured from gauge is converted to a linear relationship by plotting the logarithm of the ratio of pressure heads versus time.

From the slope of the straight line produced by this plot, the coefficient of permeability may be determined as follows

$$\mathbf{k} = \frac{\omega V g d z}{R A \theta}; \qquad \mathbf{z} = \frac{\Sigma\left[\ln\left(\frac{P_0}{P_t}\right)\right]^2}{\Sigma\left[\ln\left(\frac{P_0}{P_t}\right)t\right]}$$

Where: k = coefficient of permeability of test specimen (m/s)
ω = molecular mass of oxygen (kg/mol)
g = acceleration due to gravity ($9.81 m/s^2$)
z = slope of line determined in regression analysis
R = universal gas constant (Nm/K.mol)
A = area of concrete specimen (m^2)
P = pressure at time t (kPa)
P_0 = initial pressure at start of test (kPa)
θ = absolute temperature (K)
t = time (s)

It should be noted that the result is considered valid only if the value of regression coefficient r^2 is more than 0.99.

Fig.2 OXYGEN PERMEABILITY TEST

TABLE II: SUGGESTED RANGES FOR OXYGEN PERMEABILITY INDEX BY SOUTH AFRICAN MANUAL

OXYGEN PERMEABILITY INDEX	CONCRETE QUALITY
> 10	**Very Good**
9.5-10	**Good**
9.0-9.5	**Poor**
< 9.0	**Very Poor**

TABLE III: OPI RESULT

MIX NO.	MIX TYPE	MEAN OPI	Quality
1	**M20**	**9.43**	**Poor**
2	**M20 with FA**	**9.44**	**Poor**
3	**M40**	**9.44**	**Poor**
4	**M40 with FA**	**9.44**	**Poor**
5	**M50**	**9.44**	**Poor**
6	**M50 with FA**	**9.45**	**Poor**

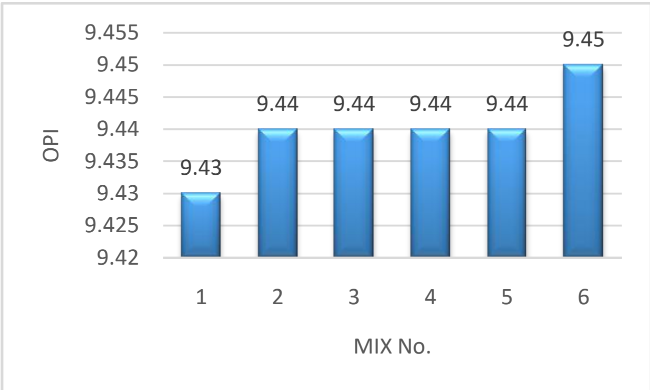

Fig. 3 OPI RESULT

From the OPI result, it was found that, there is a minor variation between various types of mixes and OPI for all mixes was found of poor quality having value between 9-9.5. This means there may be micro voids which permits oxygen to pass through specimen.

II. WATER SORPTIVITY TEST:

The sorptivity, S of the concrete is determined from the slope of the straight line produced, such that:

$$S = \frac{Fd}{Msv - Ms0}$$

Where; F is the slope of the best fit line in grams per square root of the hour
d is the average specimen thickness to the nearest 0.02 mm, in mm
Msv is vacuum saturated mass to the nearest 0.01 g of the specimen, in g
Ms_0 is mass to the nearest 0.01 g of the specimen at the initial time (t_0)
The test result is considered as valid, only if value of R^2 is more than 0.98.

Fig.4 WATER SORPTIVITY TEST

TABLE IV: SUGGESTED RANGES FOR WATER SORPTIVITY INDEX BY SOUTH AFRICAN MANUAL

WATER SORPTIVITY INDEX	CONCRETE QUALITY
< 6	**Very Good**
6-10	**Good**
10-15	**Poor**
> 15	**Very Poor**

TABLE V: SORPTIVITY RESULT

	Sorptivity ($mm/hr^{0.5}$)					Quality
Specimen	1	2	3	4	Mean	
M20	7.9	8.9	7.5	8.4	8.18	Good
M20 with FA	8.2	7.6	7.9	7.9	7.9	Good
M40	7.4	8.2	8	8.2	7.95	Good
M40 with FA	8.1	7.5	8	8.1	7.93	Good
M50	7.7	7.9	7.8	7.7	7.78	Good
M50 with FA	7.1	7	7.4	7.3	7.2	Good

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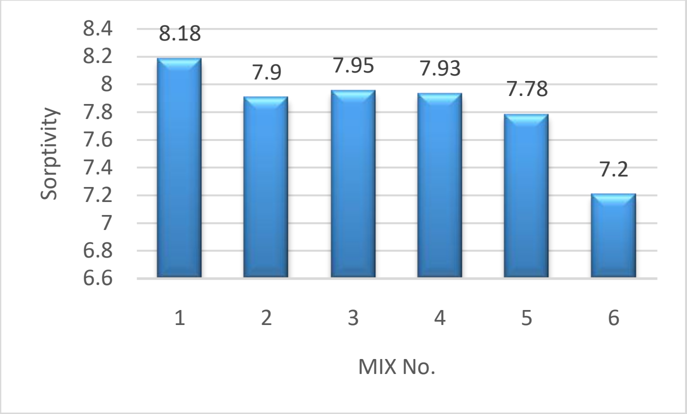

Fig. 5 SORPTIVITY RESULT

From the WSI test, it was found that;

Water Sorptivity Index for all mixes falls in good category having values between 6-10.Water sorptivity increases as w/c ratio decreases. Fly Ash mixes perform better than plain OPC mixes of same grade. M50 with Fly Ash performed better than all other mixes, while M20 with plain was found poorest than other mixes.

III. CHLORIDE CONDUCTIVITY TEST:

The chloride conductivity of concrete is calculated as follows:

$$\sigma = \frac{it}{VA}$$

Where: σ = chloride conductivity of the specimen (mS/cm)
i = electric current (mA)
V = voltage difference (V)
t = average thickness of specimen (cm)
A = cross-sectional area of the specimen (cm^2)

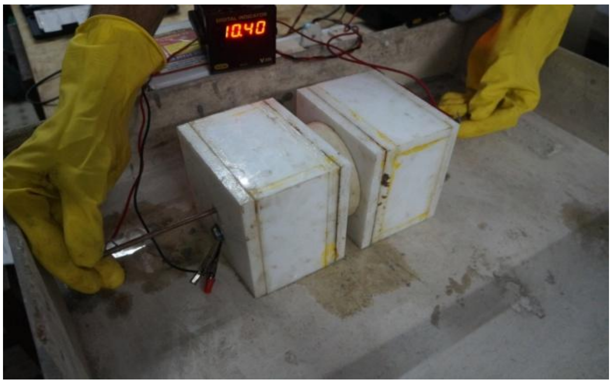

Fig. 6 CHLORIDE CONDUCTIVITY TEST

TABLE VI: SUGGESTED RANGES FOR CHLORIDE CONDUCTIVITY INDEX BY SOUTH AFRICAN MANUAL

CHLORIDE CONDUCTIVITY INDEX (mS/cm)	CONCRETE QUALITY
< 0.75	**Very Good**
0.75 – 1.5	**Good**
1.5 – 2.5	**Poor**
> 2.5	**Very Poor**

TABLE VII: CCI RESULT

CHLORIDE CONDUCTIVITY (mS/cm)						Quality
Specimen	1	2	3	4	Mean	
M20	1.28	1.18	1.15	1.28	**1.22**	Good
M20 with FA	1.04	1.11	1.04	1.1	**1.07**	Good
M40	1.02	1.05	1.06	1.12	**1.06**	Good
M40 with FA	1	1.04	0.97	0.99	**1**	Good
M50	1.05	1.04	1	1.02	**1.03**	Good
M50 with FA	0.87	0.86	0.95	0.87	**0.89**	Good

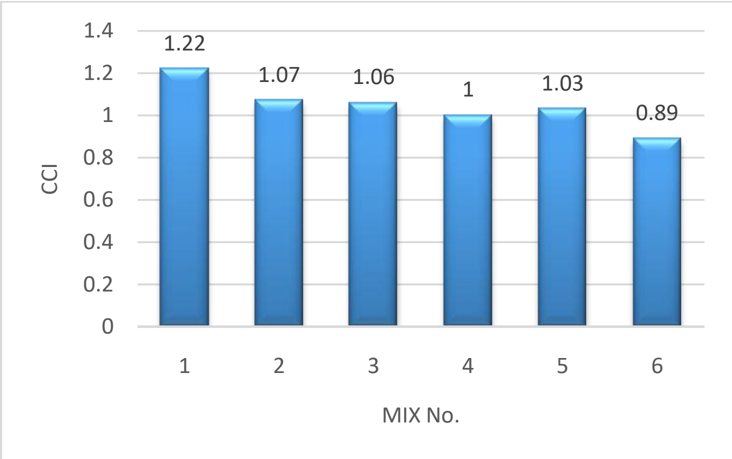

Fig. 7 CCI RESULT

From the CCI Result, it was found that;

Chloride Conductivity Index falls in good category having values between 0.75-1.5. Chloride Conductivity decreases i.e. durability increases as w/c ratio decreases and compressive strength increases.M50 with Fly Ash performed better than all other mixes, while M20 with plain was found poorest than other mixes.

V. CONCLUSIONS

From the present study, following conclusions were made:

[1] From the OPI result, it was found that, there is a minor variation between various types of mixes and OPI for all mixes was found to be of poor quality having value between 9-9.5. There may be micro voids which permits oxygen to pass through specimen.

[2] Water Sorptivity Index for all mixes falls in good category having values between 6 to 10. Water sorptivity increases as w/c ratio decreases. Fly Ash mixes perform better than plain OPC mixes of same grade by 3.65%.

[3] M50 with Fly Ash performed better than all other mixes, while M20 with plain OPC was found poorest than other mixes for WSI.

[4] Chloride Conductivity Index falls in good category having values between 0.75-1.5. Chloride Conductivity decreases i.e. durability increases as w/c ratio decreases. Fly Ash mixes perform better than plain OPC mixes of same grade by 12.6%.

[5] M50 with Fly Ash performed better than all other mixes, while M20 with plain OPC was found poorest than other mixes for CCI.

[6] Incorporation of fly ash with OPC reduced the sorptivity and chloride conductivity, means fly ash mixes have better durability than OPC mixes having nearly same strength.

VI. RECOMMENDATION

[1] This study was limited to only OPC and replacement of OPC with 30% of fly ash. For finding optimum dose of fly ash, other replacement should be carried out. Other types of mineral admixtures may be used for finding optimum dose and durability indices.

[2] As no standard tests for durability are available in Indian standards, other tests discussed in this study from various standards may be used, so that standard test procedure may be developed.

[3] By performing the durability index tests at short term and medium or long term and correlating the results service life prediction can be done.

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