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Service Life Computation of Steel Fibre Reinforced Concrete Elements Incorporating Supplementary Cementitious Materials with Diverse Water Binder Ratio

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Supplementary Cementitious Materials , Chloride Diffusion, Service Life Prediction, Chloride Penetration , Compressive Strength , Corrosion Time Period.

ABSTRACT

During the recent past ,the problem of early deterioration of concrete structures and durability of concrete structures has remained major issue posed to engineers . we have reported here the incorporation of Metakaolin ,fly ash ,GGBS and silica fume in binary and ternary blended system with diverse Water binder ratio. Various .concrete mixes with supplementary Cementitious material has been prepared and Steel Fiber & plasticizer dosage has been varied. Different types of tests carried out for determining the various durability properties such as such as RCPT, Chloride diffusion and corrosion initiation time An attempt has been made in this study to develop a tool for service life estimation of concrete structure. mathematical model for service life prediction presented here also suitable for existing concrete structures exposed to natural environment.

1. INTRODUCTION

Concrete degradation physical causes can be commonly categorized into surface wear and cracking. Surface wear is due to a difference in volume, structural loads and exposure conditions, caused by abrasion, corrosion and cavitations. Mineral admixture reduces the environmental waste management issues that factories cause. In addition, the use of mineral admixture decreases the need for cement in the building industry, resulting in less cement use and less waste from cement manufacturing plants..

Silvia B. Uchoa (2009) studied that compared and analyzed transport properties using a variety of techniques of concrete with various mineral admixture combinations were examined. A.L.G. Gastaldini G.C.Isaia etal (2010) investigated impact of time for the curing of the concrete chloride penetration behavior developed in various rice husk ash concentrations. Xuemei LiuKok , Seng Chia and Min-Hong Zhang (2011) researched on effect of chloride penetration on light weight aggregates concrete with diverse water binder ratio.ASTMC1202 test has been conducted to acknowledge penetrability remarks .[1,2,3]

Sajal K. Paul , Subrata Chaudhuri and Sudhirkumar V.(2014) found that one of the most significant factors impacting the reliability of the structure and ultimately reducing its serviceability is corrosion in RCC structural systems. This hypothesis first understands the structure of this chloride attack and identifies different process parameters. The chloride diffusion mechanism is then modelled by FEM.G. Roa-Rodriguez , W. Aperador A. Delgado (2014) made comparison between data obtained using the experiential ASTMC1202 Method and a model of lifetime estimation used to evaluate chloride diffusion in concrete structures . [4,5]

Mohamed Abdelrahman and YunpingXi (2018) researched on chloride transport mechanisms. moisture transmission by chloride transfer. tests were planned and tested for chloride ponding. Tuan Duc Le etal (2019)demonstrated the model consists of 2 dimensional chloride transport via frameworks using a probabilistic approach, taking into account. In both homogenous and heterogeneous system the spatial modification of concrete diffusion has been found .Good correlation has been found between experimental and probabilistic outputs .[6,7]

Linjian Wu etal (2020) studied the Chloride ingress into reinforced concrete (RC) exposed for harsh conditions. At different exposure times of t = 30, 70, 100, 140, and 180 days, chloride concentration has been computed and corrosion initiation time period has been monitored.J.M.P.Q.Delgado ,F.A.N.Silva etal (2020)found in their study that Chloride-attacked concrete activity was used to detect how the water-cement ratio, mineral materials, cement forms, curing time, and extent of contact influenced chloride ion penetration.. The findings showed that ANN modeling was helpful in calculating the depth of chloride penetration with chloride distribution coefficient in concrete.[8,9]

In this study, M40 Grade was chosen for different comparative purposes. Several blends (Binary & ternary)containing supplementary cementitious materials (SCM) have been prepared. The amounts of steel fibre and plasticizer used in each combination were varied to see what impact they had, and the results for different mechanical and Durability requirements were recorded.

2. EXPERIMENTAL PROGRAM

The various tests are performed to characterize the materials to be used for the production of normal concrete and supplementary cementitious materials. (SCM) concrete .The constitute materials used as cement ,natural river sand ,coarse aggregate ,super plasticizers , steel fiber , fly ash ,Grass granulated blast furnace slag (GGBS) , Metakaolin , Silica fume etc .The Properties of Cement ,fine aggregates ,coarse aggregate ,super plasticizer ,steel fibre ,fly ash, GGBS ,Metakaolin , Silica fume etc are given in table no. 1 to table no. 7. Ordinary Portland cement (OPC43 Grade) as per IS 8112:1989 were being utilized . For concrete mixing and curing, the laboratory's potable water was being utilized The natural river bed sand from Binawas Jodhpur available locally was utilized as fine aggregate .The coarse aggregate (from Kakani Jodhpur) of two sizes (20mm and 10mm) were used .The various tests requisite for the characterizing the aggregate were performed as per relevant IS Code .Glenium 51 has been used as admixture. This admixture is appropriate for high performance concrete (HPC) where good durability is required. Class f Fly ash obtained from "Suratgarh Thermal Power Station " .Rajasthan (India) .Steel fibers were obtained in the experiment from binding steel wires used in tying reinforcement bars. Steel fibers had an aspect ratio of 75.Metakaolin comes from a manufacturer called 20 Microns Limited Company. The metakaolin complies towards Pozzolona's minimum standards**.** Another substance utilized as an organic pozzolanic admixture is silica fume, also known as micro silica or condensed silica fume. ground granulated blast furnace slag. purchased from Ref steel Solutions, a supplier

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Volume 54, Issue 03, August, 2022

Table 1: Physical Properties of Cement

Property	Value Obtained
Fineness(retained on 90μm sieve)	8.1
Specific gravity	3.1
Normal consistency	30
Initial setting time (minutes)	74
Final setting time (minutes)	210

Table 2: Properties of fine aggregate

Property	Value Obtained
Specific gravity	2.4
Bulk density (kg/m^3)	1570
Fineness modulus	2.72
Gradation	Zone II as per IS 383-1970

Table 3: Property of coarse aggregate

Property	For 20 mm size	For 10 mm size
Specific gravity	2.72	2.72
Bulk density (kg/m^3)	1610	1599
Fineness modulus	6.99	6.05
Gradation	20 mm single size	10 mm single size

Table 4: Physical property of fly ash

Physical Properties	Percentage by weight
Colour	Light grey
Fineness (kg/m^3)	224.0
Specific gravity	2.23
Bulk density (kg/m^3)	700

Table 5: Physical Properties of Metakaolin

Average particle size,	1.5 µmm
Residue 325 mesh (% max)	0.5
B.E.T. Surface area, m^2/ gm	15
Specific Gravity	2.5
Bulk Density, gm/L	300+ or -30

Table 6 :Properties of GGBS

Property	Values
Colour	Off white
Specific Gravity	2.89
Bulk Weight (ton per m^3)	1.0-1.3

Table 7 : Physical Properties of Silica Fume

Physical properties	Value
Specific gravity	2.3
Bulk density	225 kg/m^3
Specific surface	20,000 m^2 /kg
Average particle size	0.14 µmm

2.1. Mix Proportion: The mix proportions were designed as per IS 10262 as shown in Tables 8 & 9

Table 8: Water Binder Ratio , Super Plasticizers and Fiber Dosage in Various Concrete Mixes

Series	w/b	SP%	Fiber %
NC40	0.37	1.5	0
NC40MK5	0.44	1.1	0.5
NC40MK10	0.44	1.1	0.75
NC40M15	0.44	1.1	0
NC40MK20	0.44	1.1	0
NC40FA5	0.43	1	1
NC40FA10	0.43	1	0.5
NC40FA15	0.43	1	0.75
NC40FA20	0.43	1	0
NC40FA5MK15	0.42	1.2	0.5
NC40FA10MK10	0.42	1.2	0.75
NC40FA15MK15	0.42	1.2	1
NC40FA10SF6	0.41	1.3	0.25
NC40FA10SF8	0.41	1.3	0.5
NC40FA10SF10	0.41	1.3	1
NC4GGBS10	0.4	1.25	0.5
NC40GGBS20	0.4	1.25	0.75
NC40GGBS30	0.4	1.25	1
NC4FA10GGBS20	0.39	1.4	0.5
NC40FA15GGBS15	0.39	1.4	1

A ES
ISSN: 2096-3246
Volume 54, Issue 03, August, 2022

Table 9: Concrete Mix Proportion (Kg Per Meter Cube) of Various Concrete Mixes

Series	Cement	Fine Aggregate	Water	Coarse Aggregate	Fly Ash	GGBS	Silica Fume	Metakaolin
NC40	433	558	160	1270	0	0	0	0
NC40MK5	411.35	534	190.52	1207	0	0	0	21.65
NC40MK10	389.7	534	190.52	1207	0	0	0	43.3
NC40M15	368.05	534	190.52	1207	0	0	0	64.95
NC40MK20	346.4	534	190.52	1207	0	0	0	86.6
NC40FA5	411.35	538	186.19	1216	21.65	0	0	0
NC40FA10	389.7	538	186.19	1216	43.3	0	0	0
NC40FA15	368.05	538	186.19	1216	64.95	0	0	0
NC40FA20	346.4	538	186.19	1216	86.6	0	0	0
NC40FA5MK15	346.4	541	181.86	1222	21.65	0	0	64.95
NC40FA10MK10	346.4	541	181.86	1222	43.3	0	0	43.3
NC40FA15MK15	303.1	541	181.86	1222	64.95	0	0	64.95
NC40FA10SF6	363.72	544	177.53	1229	43.3	0	25.98	0
NC40FA10SF8	355.06	544	177.53	1229	43.3	0	34.64	0
NC40FA10SF10	346.4	544	177.53	1229	43.3	0	43.3	0
NC4GGBS10	389.7	548	173.2	1243	0	43.3	0	0
NC40GGBS20	346.4	548	173.2	1243	0	86.6	0	0
NC40GGBS30	303.1	548	173.3	1243	0	129.9	0	0
NC4FA10GGBS20	303.1	549	168.87	1241	43.3	86.6	0	0
NC40FA15GGBS15	303.1	549	168.87	1241	64.95	64.95	0	0

2.2 Workability Of Normal And SCM Concrete : The properties of fresh concrete calculated in terms of workability. The workability of concrete is computed by slump test and compaction factor method reported in tables 10

Table 10: Workability(Slump Value and Compaction Factor) of Concrete Mixes

Series	w/b	Super plasticizer %	Fibre %	Slump (mm)
NC40	0.37	1.5	0	92
NC40MK5	0.44	1.1	0.5	80
NC40MK10	0.44	1.1	0.75	79
NC40M15	0.44	1.1	0	87
NC40MK20	0.44	1.1	0	86
NC40FA5	0.43	1	1	79
NC40FA10	0.43	1	0.5	88
NC40FA15	0.43	1	0.75	83
NC40FA20	0.43	1	0	86
NC40FA5MK15	0.42	1.2	0.5	87
NC40FA10MK10	0.42	1.2	0.75	85
NC40FA15MK15	0.42	1.2	1	83

NC40FA10SF6	0.41	1.3	0.25	86
NC40FA10SF8	0.41	1.3	0.5	82
NC40FA10SF10	0.41	1.3	1	80
NC4GGBS10	0.4	1.25	0.5	85
NC40GGBS20	0.4	1.25	0.75	82
NC40GGBS30	0.4	1.25	1	80
NC4FA10GGBS20	0.39	1.4	0.5	86
NC40FA15GGBS15	0.39	1.4	1	80

2.3 Compressive Strength Test: Cube of size 150X150X150 mm was tested after 3,7 and 28 days curing period as per IS 516. Table no 11. show compressive strength results

Table 11 : Compressive Strength Results of Various Concrete Mixes

Series	3 day compressive strength (N/mm^2)	7 day compressive strength (N/mm^2)	28 days compressive strength (N/mm^2)
NC40	24.56	36.19	50.29
NC40MK5	25	37.67	56.75
NC40MK10	25.3	40.75	58.23
NC40M15	25.36	37.44	56.37
NC40MK20	24.73	36.22	54.32
NC40FA5	25.4	37.41	53.15
NC40FA10	24.59	38.48	56.22
NC40FA15	25.33	39.07	57.97
NC40FA20	25.83	39.19	51.99
NC40FA5MK15	24.93	38.08	56.01
NC40FA10MK10	25.26	39.19	57.7
NC40FA15MK15	24.73	38.62	53.77
NC40FA10SF6	24.83	38.58	57.66
NC40FA10SF8	25.67	39.6	58.07
NC40FA10SF10	25.08	38.23	55.21
NC4GGBS10	24.86	38.63	56.84
NC40GGBS20	25.16	39.63	57.41
NC40GGBS30	24.76	38.04	55.02
NC4FA10GGBS20	25.41	38.8	56.19
NC40FA15GGBS15	24.89	36.87	54.94

2.4 RAPID CHLORIDE PERMEABILITY TEST(RCPT): The rapid chloride penetration test (RCPT) apparatus (figure1) used to test the concrete sample's resistance to the pull of chloride ions is as described in ASTM C1202. The test is carried out by inserting in the sample cells with a diameter of 100 mm and a length of 50 mm and a solution of 3.0 per cent salt and 0.3 N of sodium hydroxide. A 60 V DC voltage is

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Volume 54, Issue 03, August, 2022

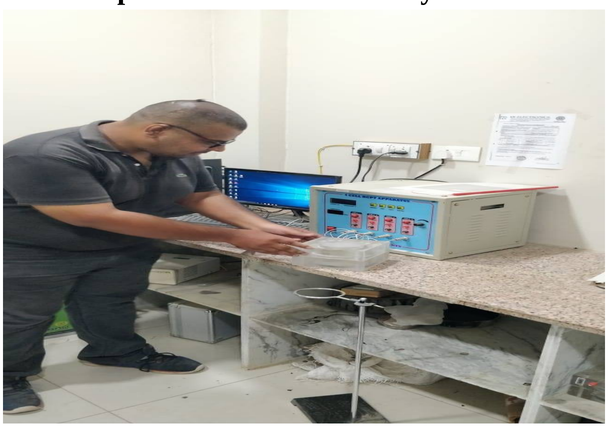
sustained across the test sample, and the charge is reported throughout the sample. Table 12 show the RCPT Result .cumulative charge transmitted throughout that time could be quantified in units of coulombs using ASTM C 1202 trapezoidal law.

$Q = 900\ (I_0 + 2I_{30} + 2I_{60} + 2I_{90} + 2I_{120} + 2I_{150} + 2I_{180} + 2I_{210} + 2I_{240} + 2I_{270} + 2I_{300} + I_{360})$
Q = charge passed (coulombs), I_0 = current (amperes) immediately after voltage is applied,
and I_{min} = current (amperes) at 30 min after voltage is applied.

Table 12: RCPT (Coulombs) of Various Specimens with Penetrability Remarks

Series	RCPT (Coulombs)	Penetrability remarks as per ASTM C1202
NC40	3210	Moderate
NC40MK5	2530	Moderate
NC40MK10	720	very low
NC40M15	1650	low
NC40MK20	1410	low
NC40FA5	3006	Moderate
NC40FA10	2004	moderate
NC40FA15	858	very low
NC40FA20	1350	low
NC40FA5MK15	1121	low
NC40FA10MK10	685	very low
NC40FA15MK15	2101	Moderate
NC40FA10SF6	1642	low
NC40FA10SF8	446	very low
NC40FA10SF10	2110	Moderate
NC4GGBS10	1141	low
NC40GGBS20	558	very low
NC40GGBS30	1223	low
NC4FA10GGBS20	621	very low
NC40FA15GGBS15	2031	Moderate

Figure 1: Rapid Chloride Permeability Test at RCC Lab



2.5 Chloride Diffusion Test (Nord Test Method NT BUILD 355) : Diffusion cell made up of reservoirs R_1 and R_2finished out of acrylic or Nylon material . The lead of the anode and the cathode mesh are separated through a hole in the reservoir's top to connect it to a D.C. power source. The specimens used to determine the diffusion coefficient were basically circular discs cut from concrete cylinders cast To suit the diffusion cell, the discs was of 100 mm (Dia) and 50 mm thick for all tests. Table 13 show chloride diffusion value of various concrete mixes.

Table 13: Chloride Diffusion Value of Various Specimens

Series	Chloride diffusion
NC40	3.52E-12
NC40MK5	3.67E-12
NC40MK10	3.71E-12
NC40M15	4.12E-12
NC40MK20	4.21E-12
NC40FA5	3.6E-12
NC40FA10	4.25E-12
NC40FA15	4.1E-12
NC40FA20	4.31E-12
NC40FA5MK15	3.69E-12
NC40FA10MK10	3.98E-12
NC40FA15MK15	3.71E-12
NC40FA10SF6	3.85E-12
NC40FA10SF8	4.17E-12
NC40FA10SF10	4.07E-12
NC4GGBS10	3.81E-12
NC40GGBS20	4.28E-12
NC40GGBS30	4.02E-12
NC4FA10GGBS20	3.87E-12
NC40FA15GGBS15	3.72E-12

2.6 Corrosion Initiation Time Period : The experimental system (figure 2) made up of a non-metal jar with 3.5% salt water added to the target level A stainless steel plate holds the cylindrical concrete sample with rebar in the centre. The applied voltage should remain constant and would be time-stamped. Concrete cylinders with dimensions of 75 mm dia * 150 mm height were used to achieve an equivalent concrete cover of 29.5mm. The time required for chloride ions to move is computed by the overall resistance of the concrete as well as the amount of current caused. As a result, calculating the current caused at regular intervals provides details about the migration of chloride and the amount of corrosion. The performance of coating was assessed relatively with specimens with Corrosion Resistant Steel (CRS) Thermo Mechanically Treated (TMT) re-bars. Table 14 show corrosion initiation time period of concrete mixes.

ISSN: 2096-3246
Volume 54, Issue 03, August, 2022

Table 14: Corrosion Initiation Time Period (Days) Value Of Various Specimens

S.NO	Series	Corrosion initiation time period (Days)
1	NC40	8
2	NC40MK5	11
3	NC40MK10	17
4	NC40MK15	14
5	NC40MK20	13
6	NC40FA5	12
7	NC40FA10	16
8	NC40FA15	14
9	NC40FA20	15
10	NC40FA5MK15	12
11	NC40FA10MK10	19
12	NC40FA15MK15	15
13	NC40FA10SF6	16
14	NC40FA10SF8	21
15	NC40FA10SF10	18
16	NC4GGBS10	12
17	NC40GGBS20	22
18	NC40GGBS30	17
19	NC4FA10GGBS20	25
20	NC40FA15GGBS15	15

Figure 2: Concrete Elements Set for Polarization Study (Accelerated Corrosion Test)

2.7 Service Life Computation Model: Predicting operational lifespan of concrete structures will help for potential maintenance and repair. The corrosion, according to Fick's principle, is caused by diffusion. Fick's law of diffusion can be written as $\frac{\partial C}{\partial t} = D \frac{\partial^2 C}{\partial x^2}$ where ,C(x,t) is the chloride ion concentration by mass of cement at a distance of 'x' from the concrete surface after 't' days to the chloride source. Dc is the chloride diffusion Co-efficient. The solution of differential equation is given by as follow $C(x,t) = C_s$ [1 - erf

$$\frac{X}{2\sqrt{D_c * t}} \text{] ------1}$$

where Dc= diffusion coefficient mm^2/year , t = time of exposure in year erf = error function , C_s = surface chloride concentration C(x,t) = chloride concentration at distance x [C(x,t)= C_x and X - Concrete cover thickness . equation 1 can be rewritten as

$$\frac{C(xt)}{Cs} = [1\text{-erf}(z)] \qquad \text{where } z = \frac{X}{\sqrt{4 * D_c * t}}$$

The value of Cs is assumed to be 0.155 mmole/cm^3 or 0.9% (solution concentration used for measuring chloride diffusion value). C(x,t) is let as the threshold chloride value (0.05% mass of concrete, [C(x,t) =Cr where Cr - Critical Chloride value to initiate corrosion] to initiate corrosion for a given concrete cover thickness. In a real structure, if 'Cr' is let to be the chloride threshold and 'X' is the concrete cover thickness, the corrosion initiation period 't' can be computed as under

$$t = \frac{X^2}{4 * D_c} * erf^{-1} * \left[\frac{Cr - Co}{Cs - Co}\right]^{-2}$$

Cr = Critical Chloride value to initiate corrosion (0.05%) ,Cs= Surface chloride Concentration (0.9% or 0.155 mmole/cm^3) ,Co= Initial chloride Concentration in concrete considered as zero

$$\frac{Cr - Co}{Cs - Co} = \frac{0.05 - 0}{0.90 - 0} = 0.055$$

Therefore, the ratio of chloride threshold value and to the surface chloride concentration is 0.055.From Gaussian error function table, the 'z' value is obtained as 1.35for erf(0.055). The corrosion initiation period has been computed using follow equation $t = \frac{X^2}{4 * D_c * z^2}$

Using the above equation , the corrosion initiation time for various types of concretes can be obtained by substituting the chloride diffusion co-efficient values, cover thickness 'X' (29.50 mm) and the 'z' value (1.35) obtained from the Gaussian error function table. The corrosion initiation period was obtained based on the chloride diffusion co-efficient and plotted a curve between RCPT values and corrosion initiation time which is presented in figure 3. Equation given below the relationship between RCPT and Corrosion initiation period.

Corrosion Initiation Period, Log(t),Yrs= -0.0008RCPT + 2.3512

From the equation above , the service life estimation of Concrete structure can be determined. The service life of different concrete types used in this study was computed based on the above equation. For computation of service life, concrete cover thickness of 29.5 mm was assumed. and Table 15 represent Service life (years) of Various specimens by Mathematical Model

Figure 3: Correlations of RCPT (Coulombs) with Corrosion initiation Time Period (Log Scale in Years)

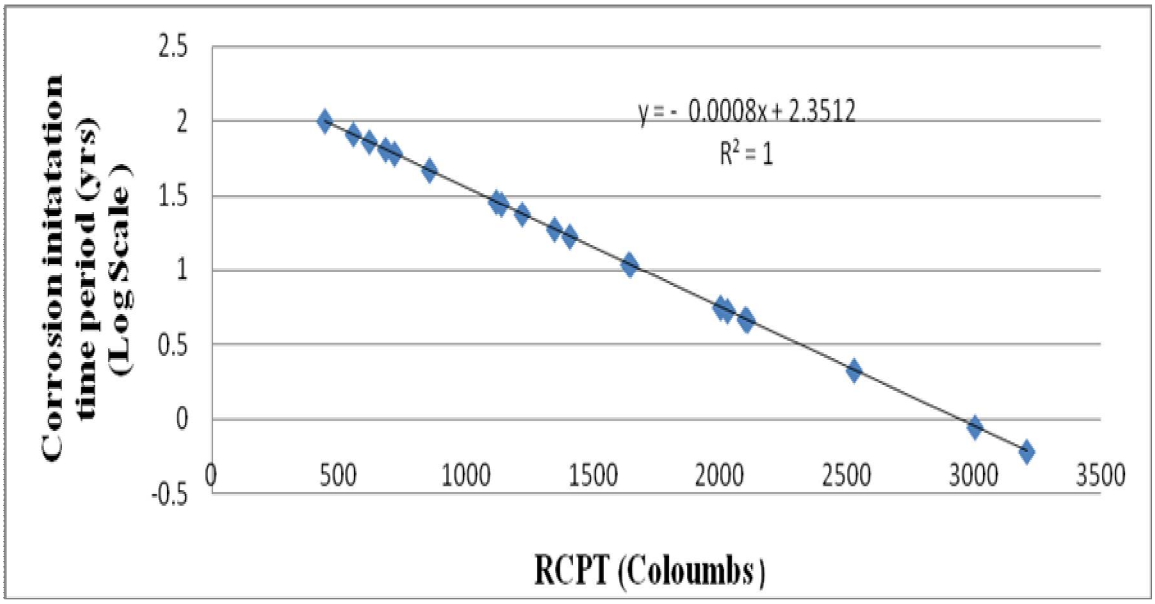


Table 15 : Service life (years) of Various specimens by Mathematical Model

Series	RCPT (Coulombs)	Service life (years)
NC40	3210	0.61
NC40MK5	2530	2.12
NC40MK10	720	59.59
NC40MK15	1650	10.74
NC40MK20	1410	16.72
NC40FA5	3006	0.88
NC40FA10	2004	5.59
NC40FA15	858	46.22
NC40FA20	1350	18.67
NC40FA5MK15	1121	28.47
NC40FA10MK10	685	63.56

NC40FA15MK15	2101	4.68
NC40FA10SF6	1642	10.90
NC40FA10SF8	446	98.72
NC40FA10SF10	2110	4.60
NC4GGBS10	1141	27.44
NC40GGBS20	558	80.32
NC40GGBS30	1223	23.59
NC4FA10GGBS20	621	71.52
NC40FA15GGBS15	2031	5.33

3 CONCLUSIONS

Utilization of cementitious products such as GGBS, fly ash, Metakaolin, and Silica fume as substitution of cement (in the optimum amount) in standard concrete results in an enhancement in strength and a diminish in porosity. This is because mineral admixtures act as filling materials in concrete mixes, reducing the pore size of the concrete blend.. Chloride penetration escalates as the porosity of the concrete up rises Compressive strength highest at 3 rd day ,7 th day and 28 day with comparison of Normal Concrete NC40 were 3.45 % ,7.22 and 11.33 % for NC40FA10GGBS20 (with 0.5 % steel fiber incorporation) . Highest reduced rate of RCPT Value (charge) has -78.66% with NC40FA10MK10 , similarly for ternary blended fly ash and silica fume NC40FA10SF8 has -86.11% reduced RCPT (Value) rate and for fly ash and GGBS Combination NC4FA10GGBS20 has -80.65 % reduced RCPT (value) rate with respect to Normal NC40 Concrete. Accelerated corrosion tests shows that SCM Concrete have good protective qualities of cover concrete over NC mixes at higher chloride concentrations Highest Corrosion initiation time period found in NC40FA10GGBS20 SCM Concrete and Lowest in NC40FA5 SCM Concrete as compared to normal concrete mix NC40. the chloride diffusion value is reduced with SCM concrete, indicating concrete has got better durability property. With application of epoxy coating on various normal and supplementary cemetitious materials (SCM) concrete specimens corrosion initiation time period has been delayed and surface coating has more enhanced the corrosion time period. reactivity of mineral admixtures is of the order: MK > SF > FA > GGBS. Model for predicting service life exposed to natural environments discussed here incorporates. service life estimation of concrete structure has been obtained. The life of the structure directly depends on the RCPT values & corrosion initiation period is directly proportional to cover thickness. The corrosion initiation time has been enhanced for the coated specimens. Service life estimation has been made based on the corrosion initiation period calculated from the diffusion coefficients of the concrete. Estimating the serviceability of concrete structures will be useful to schedule potential rehabilitation and reconstruction of concrete structures.

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