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PREDICTION OF SERVICE LIFE IN CONCRETE BY USING SCM'S WITH PARTIAL REPLACEMENT BY FLY ASH, SLAG AND SILICA FUME

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ABSTRACT

This research paper explores the use of SCMs (Supplementary Cementitious Materials) in concrete to enhance durability and predict service life. The study focuses on partial replacement of cement with fly ash, slag, and silica fume. The paper discusses durability-based design, fundamentals of corrosion, carbonation-induced corrosion, and chloride-induced corrosion. The literature review covers studies on the use of SCMs in concrete and their impact on chloride resistance and compressive strength. The paper assesses the properties of materials used in concrete and uses Life-365 software to predict the service life of concrete made of different mixes. The software analysis shows that using fly ash, slag, and silica fume individually can increase the service life of concrete, but combining SCM's can significantly improve the service life. The paper also presents the results of a compression test conducted on specimens containing different combinations of SCMs. The most preferred combination of SCM's for durability purposes is Fly ash + Silica fume. The paper recommends not performing accelerated curing before RCPT and curing specimens containing SCM's for 56 days before testing

Keyword: Supplementary Cementitious Materials (SCMs), Durability, Service Life Prediction, Concrete Corrosion, Sustainable Construction

INTRODUCTION

1.1 GENERAL

DURABILITY BASED DESIGN

Durability based design means giving importance to environmental loads in addition with structural loads. Environmental loads consist of earthquake loads and wind loads which are mentioned in the codal provisions. If we take chloride attack, carbonation attack, freeze-thaw cycles , those kind of situations are not considered by the codal provisions. Therefore, the structure will start deteriorating prematurely, it will not fulfil its service life. Therefore there will be a huge economic loss. Durability based design enhances the service life.

1.1.1 WHAT IS SERVICE LIFE OF A STRUCTURE

Service life is defined as the time the structure is able to survive as per the initial design , without and regular maintenance. Chlorides and carbon dioxide from the atmosphere get build up on the concrete surface , then after a while they start to ingress into the cover concrete , when they reach the surface of the steel , corrosion initiation begins.

Some examples of premature corrosion are shown below:

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Figure 1 *Andheri pedestrian bridge collapse in 2018*

https://www.hindustantimes.com/mumbai-news/andheri-bridge-collapse-report-blames-western-railway-staff/story-3I40PScg3jgYtfZgQ65rPK.html

Figure 2 *Silguri bridge collapse in 2018*

https://economictimes.indiatimes.com/news/politics-and-nation/another-bridge-collapses-in-west-bengal/articleshow/65715329.cms?from=mdr

Figure 3 *Junagadh bridge collapse in 2019*

https://theprint.in/india/bridge-collapses-in-gujarats-junagadh-vehicles-trapped/302280/

Figure 4 Kolkata bridge collapse in 2018

https://www.indiatoday.in/india/story/kolkata-bridge-collapse-what-is-bringing-bridges-down-in-kolkata-1332713-2018-09-05

1.2 FUNDAMENTALS OF CORROSION

Initially when the concrete is poured onto steel , a thin passive layer of oxides is formed around the steel which further protects it from corrosion, but when the structure is in harsh environments where the atmospheric content of chlorides or carbon dioxide is high , the thin layer will get damaged and the corrosion will start.

Now when we look at corrosion , there are 4 main parts involved, these are anode , cathode , ionic conductor and an electronic conductor.

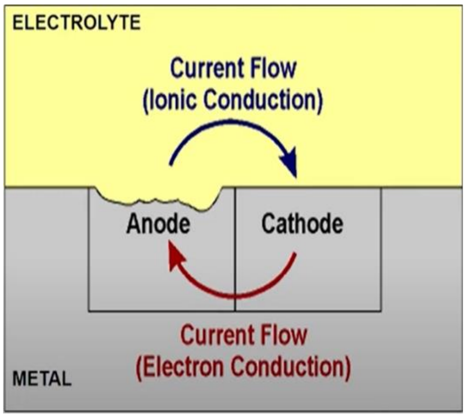

Figure 5 *corrosion cell reaction*

In the above figure as we can see the region which is being corroded is called the anode. The charge gets passed from the cathode to the anode from the metal itself. And as water is present in concrete it behaves as an electrolyte.

Anodic (oxidation) reaction

$$Fe \rightarrow Fe^{2+} + 2e^{-}$$

Cathodic (reduction) reaction

$$\frac{1}{2}O_2 + H_2O + 2e^{-} \rightarrow 2(OH)^{-}$$

Figure 6 *half cell reactions*

So in the above figure we can see the anodic reaction happening on the steel surface , we can see that Fe2+ and 2 electrons getting liberated , now the liberated electrons are being absorbed at the cathodic side where there is enough oxygen and moisture and it forms hydroxide ions , which then react with Fe2+ to form rust.

1.3 CHLORIDE INDUCED CORROSION

There are many factors which define chloride induced corrosion such as chloride surface concentration, chloride build up rate , chloride diffusion coefficient and chloride threshold. Also a term called decay constant , which is linked with the hydration of concrete , generally we take complete hydration to be about 25 years , after that the diffusion coefficient is taken as constant.

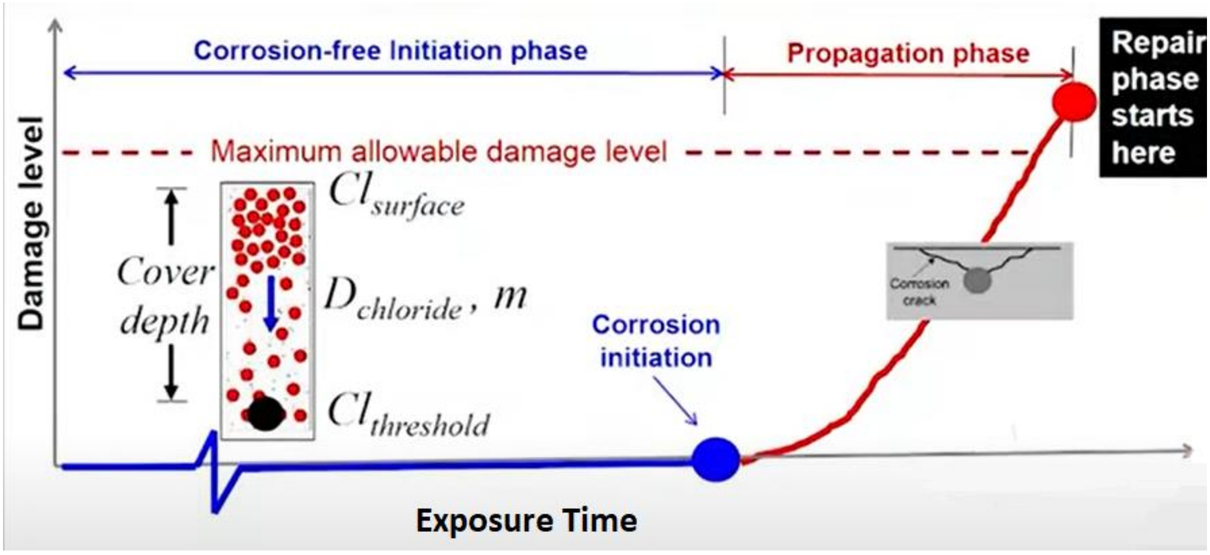

Figure 7 *corrosion due to chloride*

As we can see from the above figure , the blue dot indicates the corrosion initiation stage , that means the chloride ions have reached the steel surface and the corrosion has begun, the period after this is known as the propagation phase till the red dot , which means that corrosion is within limits , we usually take propagation phase as 6 years. After the 6 year mark has reached , repair is unavoidable.

1.3.1 MECHANISM OF CHLORIDE INDUCED CORROSSION

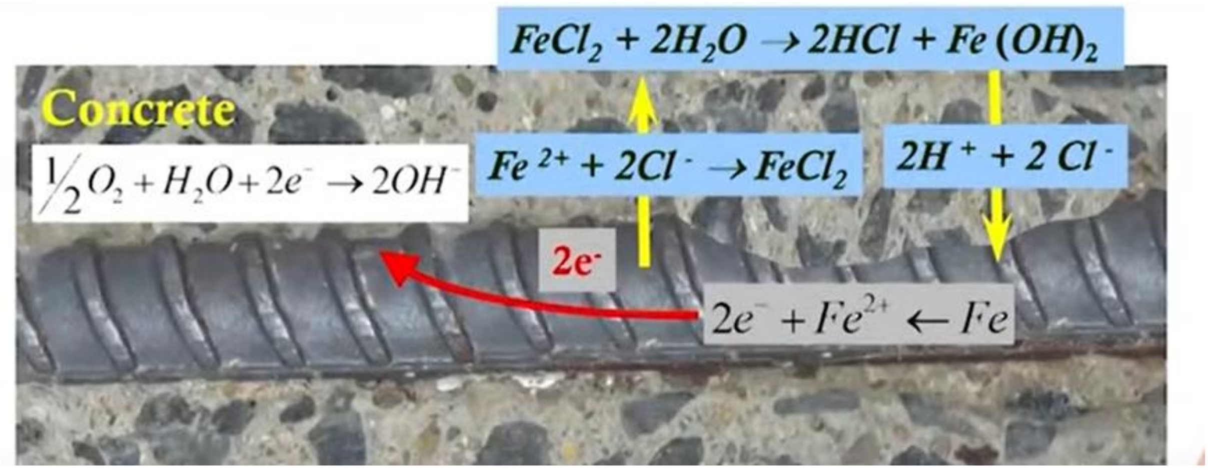

Figure 8 *Chloride corrosion reactions*

When we have enough chloride ions reaching the steel surface , it will react with iron ions and form Ferrous chloride , which then reacts with moisture present in the concrete and form hydrogen chloride and ferrous hydroxide , the HCl further reduces the ph of the concrete and liberates into hydrogen and chloride ions , those chloride ions again react with Fe+ ions to form ferrous chloride , so this process is endless till Fe+ runs out or chloride runs out .

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1.4 CARBONATION INDUCED COROSSION

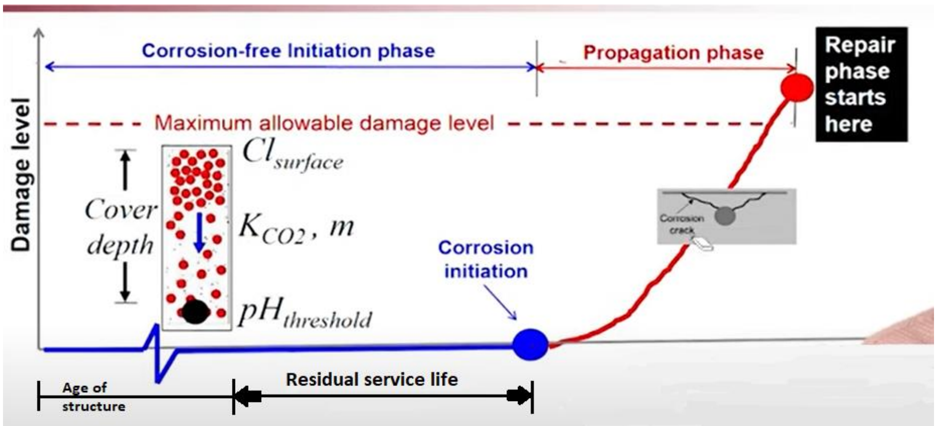

Figure 9 *Carbonation induced corrosion*

The blue region in the above figure indicates that no corrosion has started yet. When the carbon reached the steel surface , the ph will drop from 13 to 9 , that is when the corrosion will initiate as shown by the red dot. The carbonation absorption happens most when the relative humidity is 60 to 70 percent.

1.4.1 MECHANISM OF CARBONATION INDUCED CORROSION

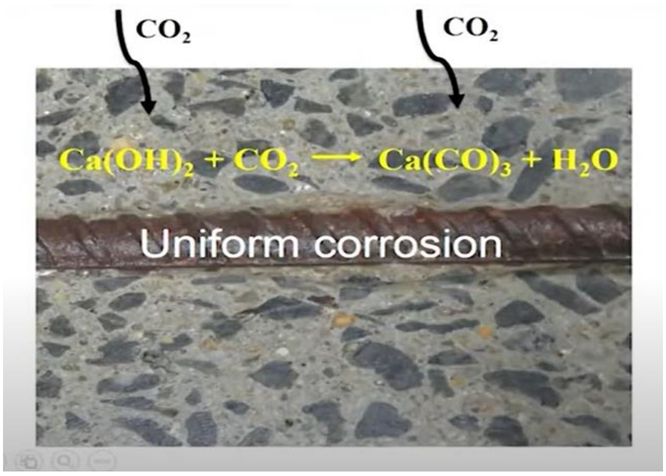

Figure 10 *Carbon dioxide ingress*

Initially when the carbon dioxide enters the concrete, it reacts with water to form carbonic acid , which then reacts with calcium hydroxide , so eventually in this reaction OH- ions will get used up , so significantly the pH will reduce and the steel will no longer be protected . Here are the reactions as mentioned :

- $CO_2 + H_2 O \rightarrow H_2CO_3$ (carbonic acid)
- $H_2CO_3 + \mathrm{Ca}(OH)_2 \rightarrow \mathrm{Ca}\ CO_3 + 2\ H_2 O$
- $H_2CO_3 + \mathrm{CaO} \rightarrow \mathrm{Ca}\ CO_3 + H_2 O$

LITERATURE REVIEW

2.1 General

This chapter provides the literature review on the publications of the topics from various referred journals

2.2 Literature review

Kim Yong Ann et al. (2007) have used calcium nitrate as corrosion inhibitors and found out that it significantly increased the threshold value. Also, they have found that corrosion initiates at steel concrete interface where there is weak bond between the two. The CTL (chloride threshold level) value depends on how it is expressed, such as the mole ratio of [Cl-:[OH-], free chloride, or total chloride. The CTL has been expressed as free chloride or [Cl-]:[OH-] in many previous studies, as being very widely ranged. The free chloride content or [Cl-]:[OH-] has the disadvantage of poor accuracy and repeatability. It fails to consider the participation of bound chloride in sustained corrosion and the buffering capacity of the cement matrix [1].

Yifeng Ling et al. (2019) have used fly ash and slag as partial cement replacement and found out the effect it has on the chloride resistance of the concrete. They found that by increasing the fly ash content the chloride resistivity increased proportionately, also increasing the slag content above 40 % made the resistivity decline. A systematic study on the chloride penetration resistance and binding capacity of cementitious materials containing varying proportions of low-calcium fly ash or blast-furnace slag is presented. The results show that a larger water/ binder ratio of cementitious materials can enhance its binding capacity but reduce chloride resistance regardless of binder type [2].

Prinya Chindraprasit et al.(2011) have studied the effect of fly ash fines on compressive strength and pore size of blended cement paste. They have used Class F fly ash with two fineness, an original fly ash and a classified fly ash, with median particle size of 19.1 and 6.4μm respectively were used to partially replace portland cement at 0%, 20%, and 40% by weight. The water to binder ratio (w/b) of 0.35 was used for all the blended cement paste mixes. Test results indicated that the blended cement paste with classified fly ash produced paste with higher compressive strength than that with original fly ash. The porosity and pore size of blended cement paste was significantly affected by the replacement of fly ash and its fineness[3].

R.B Holland et al (2016) have used SCM's (supplementary cementitious materials) as a partial cement replacement. They have found that creating a highly dense, impermeable concrete improved service life and was highly corrosion resistant. Also using low w/c ratio with SCM's gives higher durability than with only OPC . The inclusion of SCM's significantly influences the compressive strength of the high strength mix. The effect of silica fume is to enhance the compressive strength of concrete at all ages, particularly at the age of 28 to 90 days. The general effect of the different SCM's on the elastic modulus of high strength concrete is nominal compared to their effect on strength [4].

JJ. Brooks et al (2000) have studied the effect of admixtures on the setting times of high strength concrete. They found that the setting times of the high-strength concrete were generally retarded when the mineral admixtures replaced part of the cement. The inclusion of GGBS at replacement levels of 40% and greater resulted in significant retardation in setting times. In general, as replacement levels of the mineral admixtures were increased, there was greater retardation in setting times. However, for the concrete containing MK, this was only observed up to a replacement level of 10% [5].

Martin perez et al.(2000) have studied the factors influencing the chloride binding capacity in concrete. They found that chloride salt and total chloride content to be the most important factors governing binding. Binding also increased with increases in water/cement ratio, curing temperature and age. Similar, though less pronounced, trends were observed when chlorides were introduced externally by immersing thin discs of hardened, but relatively immature, cement paste [6].

R.G Pillai et al. (2018), They have studied the service life and life cycle assessment of Reinforced concrete with fly ash and limestone calcined clay cement. They have used 3 combinations namely 100% OPC, 70% OPC with 30 % fly ash (PFA), Lime stone calcined clay cement (LC3) , LC3 was a composition of 50% OPC , 31% calcined clay , 15% limestone , and 4 % gypsum . They have found out that PFA and LC3 systems showed lower chloride diffusion coefficients. They also found out that the carbonation rate was higher than with the only OPC mix design [7].

Sripriya R. (2018) have studied the effect of using Limestone calcined clay cement and fly ash replacement on the concrete life cycle assessment. In this study on chloride-induced corrosion in various concrete mixes, the service life parameters such as chloride diffusion coefficient and ageing coefficient (m) of the concrete, and chloride threshold of the steel-cementitious interface were determined experimentally and used to estimate the probabilistic service life (conservatively taken as corrosion initiation time) of two concrete categories (M35 and M50). The Chloride threshold and Diffusion coefficient and their synergistic effect on service life should be considered while selecting alternate binders [8].

Nial Holmes et al. (2015), have done a review on cathodic protection systems on RC structures. Impressed current cathodic protection system (ICCP) have been used commonly for reinforced concrete structures as the resistance of concrete requires more controlled protection currents. Activated titanium mesh anode systems are the most regularly used due to their reliability. They conclude that further research needs to be done on the potential for intermittent sources provisioning adequate protection renewable energy based cathodic protection systems [9].

Deepak. Kamde et al. (2021) have studied the corrosion initiation mechanisms and service life estimation of concrete systems with fusion bonded epoxy coated steel exposed to chlorides. They have found that the service life of RC system with FBE coated steel with a coating thickness of 200 and 100 mm was about 30% and 50%

less than the service life of RC systems with FBE coated steel with coating thickness of 300 mm. Whereas, the service life of RC systems with FBE coated steel rebars with damage was found to be 35% less than the service life of RC systems with uncoated steel rebars, which is about 70% less than RC systems with FBE coated steel rebars. Their study suggests avoiding the use of FBE coated rebars unless adequate coating thickness is provided and damage to coating can be avoided [10].

C.K. Chiu et. al (2008) have studied the effect of carbonation on RC beam and column, they have found out the best maintenance plans for extending the service life of the element. They have created an algorithm which minimizes the life cycle cost of the structure. They have used genetic algorithm and immune algorithm and compared the results from the two. The algorithms give varied maintenance plan so that the user has a number of options to choose from [11].

Syed Basha et. al (2014) have studied the effect of Fly ash on compressive strength of concrete cubes. They have done mix design for M25 and M30 concrete. They have replaced cement by fly ash in percentages of 10%, 20%,30% and 40%. They have checked the compressive strength for each of the percentage in 7, 14 ,21 and 28 days. They have found out that at 7 days, the strength significantly reduces with the increase of fly ash percentage. Even at 14 days, the strength is reduced as the percentage of fly ash increases. Same thing is being observed at 21 and 28 days [12].

Atul Dubey et. al (2012) have studied the effect of blast furnace slag powder on the compressive strength of concrete. They have replaced cement by 5 to 30%. In their study they have found that slag reduces the strength of the concrete by some little amount. They have designed for M30 concrete using 43 grade OPC. They have concluded that the best percentage replacement of cement to be about 15%, which does not drastically decrease the strength at 28 days [13].

Muneeb Qureshi et. al (2016) have studied the effect of silica fume on the strength and durability properties of concrete. They have also studied the effect on water absorption, splitting tensile strength and chloride resistivity of concrete. It was seen that by increasing the water – cement ratio, the compressive strength reduced, when the silica content was increased, the compressive strength was increased by some amount. Silica fume content did not affect the tensile strength of the concrete specimens. The chloride resistivity was about 830% higher at 15% silica fume when compared to normal concrete [14].

Rob. B. Polder et. al (2013) studied the service life of cathodic protection systems installed in about 150 structures in Netherlands. They found out that out of the 150 systems, 50 were operable for over 10 years. 65 systems worked well without any maintenance. They have concluded that cp systems need maintenance at every 15 years of age to keep it running indefinetly [15].

2.3 Summary of the past work

After studying the previous works , we can infer that using SCM's in concrete not only enhances the strength but also increases the service life substantially. The service life of the structure depends on many factors which include the cover depth, surface chloride concentration , chloride buildup rate, chloride diffusion coefficient, using SCM's has an effect on the diffusion coefficient of the concrete. Preventive methods like fusion bonded epoxy steel is also not affective , as it gets damaged during the manufacturing process and allowing corrosion to happen , other repair strategies like alkaline slurry coating , zinc coating on concrete surface do provide extend in the service life , zinc coating on surface only works if the cover depth is less than 40 mm. Also the experimental analysis on chloride quantity varies from different type of experiments . some only consider free chlorides , some consider bound chlorides that do no affect the corrosion process. Also chloride threshold values differ from test to test . The most easy way to overcome all these problems are to use Mix design which incorporate SCM's and give the best service life.

2.4 Need for investigation

From the literature study, the scope of present study identified are as follows:

- To predict the service life of concrete made of different mix using life 365 software
- To find the best combination of SCM's used which will give optimized service life .
- Need to find the optimized mix design of SCM's such that the number of times maintenance required on a structure will be minimum.

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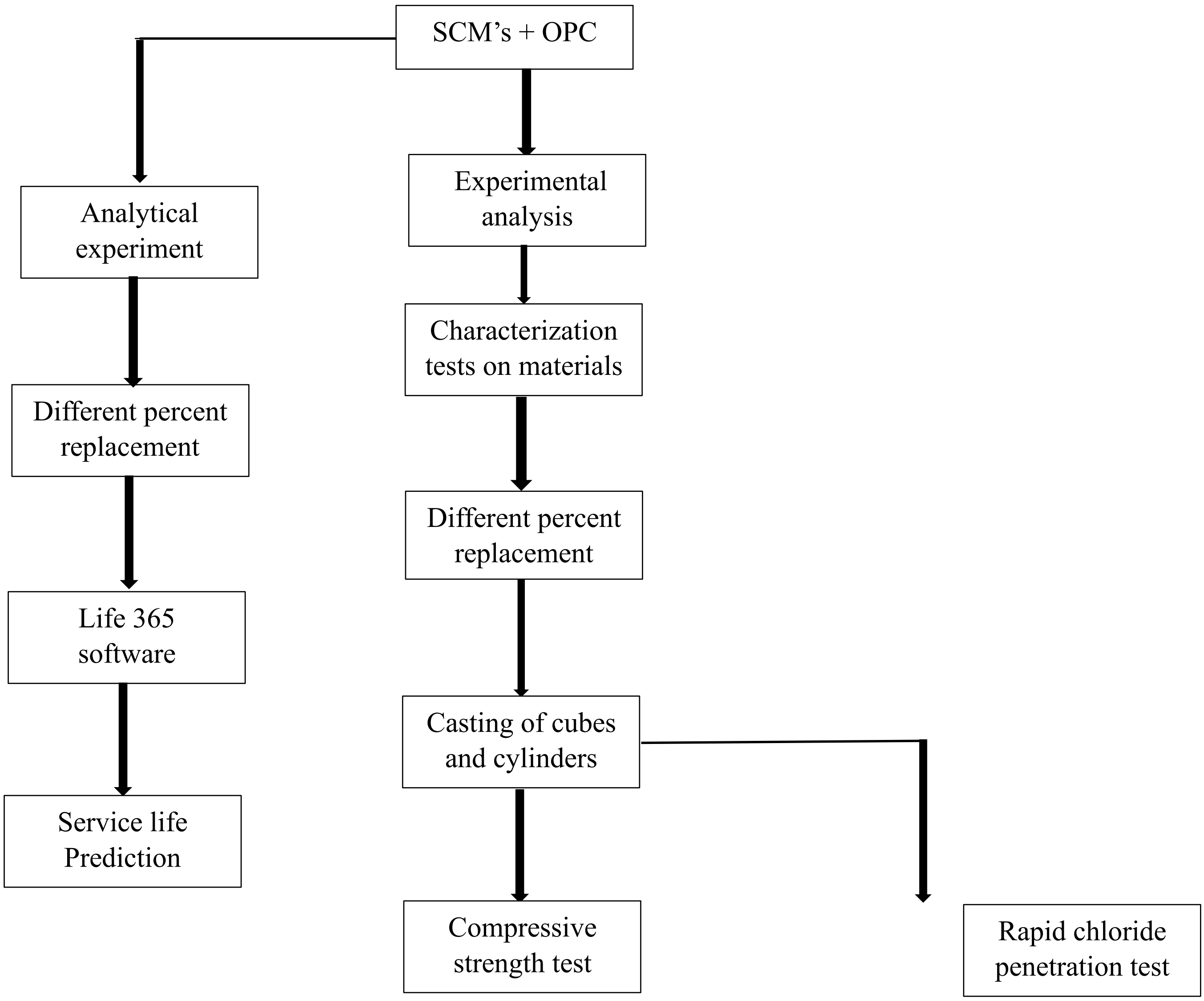
OBJECTIVES AND SCOPE OF DISSERTATION

3.1 GENERAL

The objective of this study is to find the optimized combination of SCM's(supplementary cementitious materials) used in concrete to give better service life in life 365 software.

3.2 METHODOLOGY



3.3 SCOPE OF THE INVESTIGATION

- Analysis of service life is restricted to be computed using in life 365 software
- The scope of this study is limited to durability analysis affecting due to only chloride ingress in concrete
- The SCM's considered for the present study are fly ash , Slag and silica fume

ASSESSMENT OF PROPERTIES OF MATERIALS

4.1 GENERAL

The materials as ingredients of concrete and their physical, chemical and morphological properties play very important role in workability, mechanical strength and durability of the concrete. This chapter describes the properties of materials assessed using the procedures as per the standard codes of practice and specifications of the properties of materials used.

4.2 MATERIALS USED

- Cement 43 grade
- Fly ash grade I
- Ground granulated blast furnace slag
- Silica fume
- M sand zone II
- Coarse aggregate (maximum nominal size 20mm)

4.2.1 CEMENT 43 GRADE conforming to IS 8112: 2013

Ordinary Portland cement of 43 grade is manufactured by intimately mixing together calcareous and argillaceous and other silica, alumina or iron oxide bearing materials burning them at a clinkering temperature and grinding the resulting clinker so as to produce the cement complying with IS code 8112: 2013.

4.2.2 FLY ASH GRADE I

Coal fly ash, also sometimes known as "pulverized fuel ash," is a fine-grained particulate material collected from the flue gases of coal-fired electrical power plants, which has appealing properties as an SCM. Since its earliest use in the 1930s in the U.S, the use of fly ash in concretes has spread to be accepted, and standardized, in almost every country of the world. Fly ash properties and compositions are governed by standards including ASTM C618 and others. Notably, fly ashes can be categorized according to ASTM C618 as Class C or Class F by their oxide compositions. However, both the chemistry and the particle-level properties of fly ash are complex, variable, and in need of detailed analysis and characterization to enhance and optimize the use of this material in modern cements and concretes. In portland cement concrete, fly ash tends to give enhanced rheology and long-term performance, but at the cost of early-age strength. Most fly ash-containing concretes have substitution rates of up to 30% fly ash for cement, but high volume blends with as much as 70% fly ash have also been developed

4.2.3 Ground granulated blast furnace slag

Blast-furnace slag (BFS) is a by-product of the manufacture of pig iron in the blast furnace. It forms by fusion of the gangue material of the iron ore, mainly silica and alumina compounds, with calcium and magnesium oxides of the thermally decomposed carbonatic flux and combustion residues of the coke. These reactions take place at temperatures between 1300°C and 1600°C. The slag floats on top of the liquid iron and is tapped at regular intervals. When leaving the blast furnace, the molten BFS has a temperature of around 1450°C and is cooled, either slowly in open pits or rapidly through granulation. Granulation involves the rapid quenching and mechanical dissemination of the molten slag with water jets. Air cooled slag is essentially crystalline and poorly reactive. The water cooled granulated blast-furnace slag (GBFS) has a maximum particle size around 5 mm and is predominantly vitreous. This high glass content is the prerequisite for the latent hydraulic reactivity of GBFS, which, when ground, makes it an excellent SCM.

4.2.4 Silica fume

Silica fume, also known as microsilica, is a by-product from production of silicon metal and ferrosilicon alloys from high purity quartz, along with carbonaceous materials such as coke or wood chips, in electric arc furnaces. According to ACI 234R-06, fumes from other types of silicon alloys should be avoided. It is typically produced in small volumes; world production is approximately two million tons per annum with utilization slightly higher than 1 million tons. Silica fume is characterized by its high amorphous silica content (typically >90%) as well as its extremely fine and spherically shaped particles. Due to its impact on rheology and its promotion of nucleation and participation in early-age hydration, silica fume is often combined with fly ash or GGBFS to compensate for their slower rates of hydration in high-performance concretes.

4.2.5 M sand

Manufactured sand (M-Sand) is a substitute of river sand for concrete construction . Manufactured sand is produced from hard granite stone by crushing. The crushed sand is of cubical shape with grounded edges, washed and graded to as a construction material. The size of manufactured sand (M-Sand) is less than 4.75mm. Due to the depletion of good quality river sand for the use of construction, the use of manufactured sand has been increased. Another reason for use of M-Sand is its availability and transportation cost. Since manufactured sand can be crushed from hard granite rocks, it can be readily available at the nearby place, reducing the cost of transportation from far-off river sand bed.

4.3 Tests on materials

4.3.1 Specific gravity test on cement conforming to IS Code 2720 part 3

Apparatus used is pycnometer of 50ml

W1 = weight of empty bottle = 30g

W2 = weight of cement + bottle = 55g

W3 = weight of cement + kerosene = 92g

W4 = weight of kerosene + empty bottle = 78g

Specific gravity = $\frac{w_2 - w_1}{(w_2 - w_1) - (w_3 - w_4)} \times 0.79$

Specific gravity = 2.87

4.3.2 Specific gravity test on Fly ash conforming to IS Code 1727 (1967)

Apparatus used is pycnometer of 50ml

W1 = weight of empty bottle = 30g

W2 = weight of cement + bottle = 55g

W3 = weight of cement + kerosene = 88g

W4 = weight of kerosene + empty bottle = 78g

Specific gravity = $\frac{w_2 - w_1}{(w_2 - w_1) - (w_3 - w_4)} \times 0.79$

Specific gravity = 2.11

4.3.3 Specific gravity of slag conforming to IS 12089 – 1987

Apparatus used is pycnometer of 50ml

W1 = weight of empty bottle = 30g

W2 = weight of cement + bottle = 55g

W3 = weight of cement + kerosene = 94g

W4 = weight of kerosene + empty bottle = 80g

Specific gravity = $\frac{w_2 - w_1}{(w_2 - w_1) - (w_3 - w_4)} \times 0.79$

Specific gravity = 2.87

4.3.4 Specific gravity of silica fume conforming to IS15388-2007

Apparatus used is pycnometer of 50ml

W1 = weight of empty bottle = 30g

W2 = weight of cement + bottle = 54g

W3 = weight of cement + kerosene = 88g

W4 = weight of kerosene + empty bottle = 78g

Specific gravity = $\frac{w_2 - w_1}{(w_2 - w_1) - (w_3 - w_4)} \times 0.79$

Specific gravity = 2.16

4.3.5 Specific gravity of coarse aggregate

W1= Weight of saturated aggregates + basket in water = 1850g

W2 = Weight of basket in water = 650g

W3 = Weight of saturated aggregates in air = 2006g

W4 = Weight of oven dry aggregates in the air = 1993g

Apparent specific gravity = $\frac{w_2 - w_1}{w_3 - (w_1 - w_2)}$ =2.7

4.3.6 Specific gravity of Fine aggregates

Apparatus used is pycnometer of 1000ml

W1 = weight of empty bottle = 630g

W2 = weight of fine agg. + bottle = 1220g

W3 = weight of fine agg. + water = 1880g

W4 = weight of water + empty bottle = 1520g

Specific gravity = $\frac{w_2 - w_1}{(w_2 - w_1) - (w_3 - w_4)}$

Specific gravity = 2.565

LIFE 365 SOFTWARE

5.1 General

The Life-365™ v1.0 program and manual were written by E. C. Bentz and M. D. A. Thomas under contract to the Life-365 Consortium I, which consisted of W. R. Grace Construction Products, Master Builders, and the Silica Fume Association. The Life-365™ v2.2.3 program and manual are adaptations of these documents, and were written by M. A. Ehlen, Ph.D. under contract to the Life365 Consortium III, which consists of Master Builders, Cortec, Epoxy Interest Group (Concrete Reinforcing Steel Institute), Euclid Chemical, Grace Construction Products, National Ready mixed Concrete Association, Sika Corporation, Silica Fume Association, Slag Cement Association

5.2 Predicting chloride ingress due to diffusion

The model predicts the initiation period due to diffusion of chloride ions in concrete. Fick's law is used to determine the initiation time, assuming that no cracks are present in the concrete, the equation is given as follows:

$$\frac{dC}{dt} = D.\frac{d^2C}{dt^2}$$

the chloride content

D = the apparent diffusion coefficient,

x = the depth from the exposed surface,

t = time

The chloride diffusion coefficient is a function of both time and temperature, and Life-365 uses the following relationship to account for time-dependent changes in diffusion

$$\mathrm{D}(t)=D_{ref}\left(\frac{t_{ref}}{t}\right)^{2}$$

D(t) = diffusion coefficient at time t

Dref = diffusion coefficient at time t_{ref} (= 28 days in Life-365)

m = diffusion decay index, a constant.

5.3 Input parameters for predicting the initiation period

- Geographic location
- Type of structure and nature of exposure
- Depth of clear concrete cover to the reinforcing steel
- Details of each protection strategy scenario, such as water-cement ratio, type and quantity of supplementary cementitious materials and corrosion inhibitors, type of steel and coatings

5.4 Surface Chloride Build Up rate

The software automatically determines the maximum surface chloride concentration and the time it takes to reach that concentration. The user can also input those variables manually.

5.5 Temperature Profile

The software automatically determines the yearly average temperature based on the location set by the user, alternatively the user can set a location and also manually input the temperature variations across each month.

The value of hydration coefficient (m) is based on data from the University of Toronto and other researched work and it decreases the diffusion coefficient slowly over the course of 25 years, after which point Life-365 holds it constant at the 25-year value,assuming that hydration is complete.

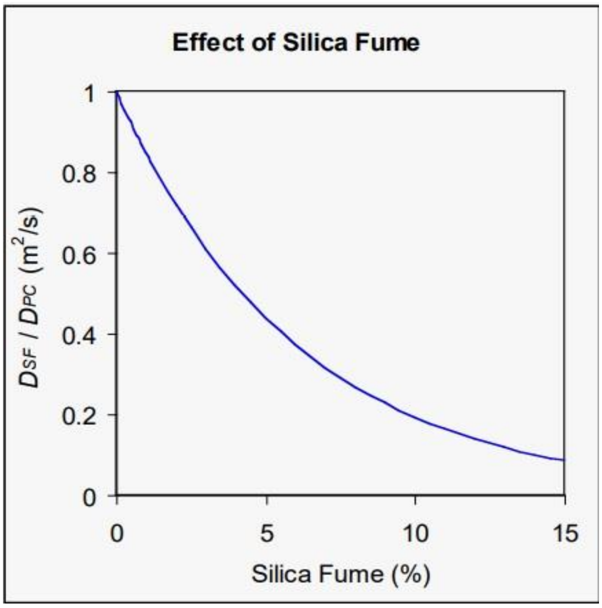
The value of Chloride threshold is commonly used for service-life prediction purposes (and is close to a value of 0.50 percent chloride based on the mass of concrete.

5.6 Effect of Silica Fume

The addition of silica fume produces significant reduction in the permeability and diffusivity of concrete. Life-365 applies a reduction factor to the value calculated for ortland cement, D_{pc}, based on the level of silica fume in the concrete. The following relationship has been developed:

$$D_{sf} = D_{pc}.e^{-0.165\,SF}$$

The relationship is only valid up to replacement levels of 15-percent silica fume. The model will not compute diffusion values for higher levels of silica fume.

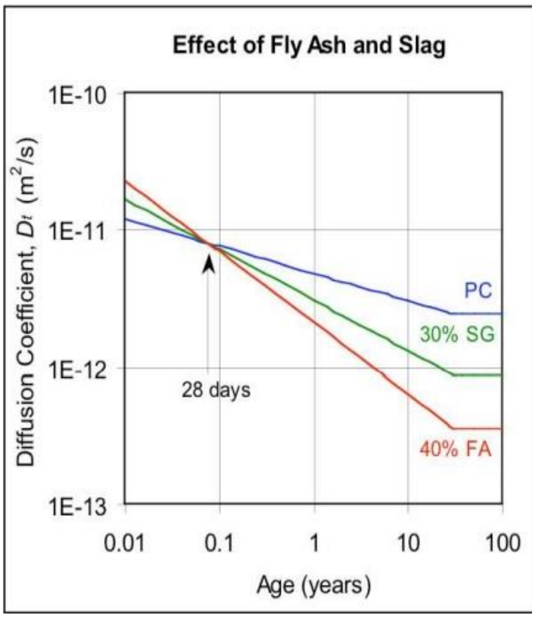


5.7 Effect of Fly Ash and Slag

Neither Fly Ash nor Slag are assumed to affect the early-age diffusion coefficient, D28, or the chloride threshold. However, both materials impact the rate of reduction in diffusivity and hence the value of 'm'. The following equation is used to modify m based on the level of fly ash or slag in the mixture:

$$m = 0.2 + 0.4\,(\%F.A/50 + \%\ slag/70)$$

The relationship is only valid up to replacement levels of 50 percent fly ash or 70 percent slag and 'm' itself cannot exceed 0.60.


Effect of Fly Ash and Slag
Diffusion Coefficient, D_t (m^2/s)
1E-10
1E-11
1E-12
1E-13
0.01
0.1
1
10
100
Age (years)
28 days
PC
30% SG
40% FA

RESULTS AND DISCUSSION

SOFTWARE ANALYSIS

6.1 Software Analysis

As we are using SCM's like fly ash, slag and silica fume, we need to check what effects will each one have when mixing in concrete. Therefore to begin with we have to input different percent replacement of cement by each SCM separately in Life 365 software and check the calculated service life.

6.2 Adding Fly ash

It was observed that when using Fly ash, at 30% replacement level, the maximum service life achieved was about 12 years. The tiny particles of Fly ash are able to fill the small voids and produce dense concrete. This makes it less permeable to water thereby increasing the durability of concrete. It also lowers the heat of hydration, in turn reducing shrinkage and thermal cracking. The concrete also becomes more resistant to sulphate attack and alkali aggregate reactivity.

Input parameters

- Geographic location = Mumbai
- Type of structure = bridge girder
- Average temperature of each month
- Water cement ratio = 0.43
- Percent cement replacement

Table 6.1

Percent replacement	**Chloride diffusion coefficient (m^2/sec)**	**Hydration coefficient**	**Chloride threshold value (% wt. conc)**	**Initiation years**	**Propagation years**	**Service life (years)**
5% replacement	8.87×10^{-12}	0.24	0.05	3.6	6	10
10% replacement	8.87×10^{-12}	0.28	0.05	3.8	6	10
15% replacement	8.87×10^{-12}	0.32	0.05	4.2	6	11

20% replacement	8.87×10^{-12}	0.36	0.05	4.7	6	11
25% replacement	8.87×10^{-12}	0.4	0.05	5.2	6	12
30% replacement	8.87×10^{-12}	0.44	0.05	5.8	6	12

6.3 Percent replacement by Slag

It was observed that, when replacing cement with Slag, the software predicted the service life to be about 11 years when 30% of cement was replaced by Slag. We can conclude that it does not make any difference in the service life when used individually.

Table 6.2

Percent replacement	**Chloride diffusion coefficient (m^2/ sec)**	**Hydration coefficient**	**Chloride threshold value (% wt. conc)**	**Initiation years**	**Propagation years**	**Service life (years)**
5% replacement	8.87×10^{-12}	0.23	0.05	3.5	6	10
10% replacement	8.87×10^{-12}	0.26	0.05	3.7	6	10
15% replacement	8.87×10^{-12}	0.28	0.05	3.8	6	10
20% replacement	8.87×10^{-12}	0.31	0.05	4.1	6	11
25% replacement	8.87×10^{-12}	0.34	0.05	4.4	6	11
30% replacement	8.87×10^{-12}	0.37	0.05	4.8	6	11

6.4 Percent replacement by silica fume

It was observed that, when replacing cement with silica fume, the software predicted the service life to be about 24 years when 10% of the cement was replaced by silica fume. Silica fume is a very fine material which occupies small pores in concrete, thus making it resistant towards chloride ion penetration. When silica fume is added to concrete, it results in a significant change in the compressive strength. This is mainly due to aggregate-paste bond improvement and enhanced microstructure.

Table 6.3

Percent replacement	**Chloride diffusion coefficient (m^2/sec)**	**Hydration coefficient**	**Chloride threshold value (% wt. conc)**	**Initiation years**	**Propagation years**	**Service life (years)**
2% replacement	6.21×10^{-12}	0.3	0.05	5.2	6	11.2
4% replacement	5.14×10^{-12}	0.35	0.05	6.8	6	12.8
6% replacement	3.37×10^{-12}	0.35	0.05	9.8	6	15.8
8% replacement	2.21×10^{-12}	0.35	0.05	14.2	6	20.2
10% replacement	1.74×10^{-12}	0.35	0.05	18.1	6	24.1

6.5 Combination of SCM's

6.5.1 Fly Ash + Slag

When fly ash and slag are used, both replacing 25% of cement each, the service life predicted by the software comes out to be about 18 years. Individually it was seen that fly ash and slag both do not contribute so much to the service life but when used together they have significantly improved the service life.

6.5.2 Fly ash + Silica fume

When Fly ash and Silica fume are used, each replacing cement by 30% and 10% respectively, the service life predicted by the software is about 29.5 years. It can be concluded that Fly ash and silica fume are one of the preferred combinations to increase the service life substantially.

6.5.3 Slag + Silica Fume

When using Slag and Silica fume, each replacing 25% and 10% respectively, the service life predicted by the software is about 36.5 years. It can be concluded that using this combination is the preferred choice to use to increase the durability by 300% as compared to OPC.

Table 6.4

Percent replacement	**Chloride diffusion coefficient (m^2/sec)**	**Hydration coefficient**	**Chloride threshold value (% wt. conc.)**	**Initiation years**	**Propagation years**	**Service life (years)**
100% OPC	8.87×10^{-12}	0.26	0.05	5.4	6	11.4
50% Fly ash	8.87×10^{-12}	0.6	0.05	15.3	6	21.3
50% slag	8.87×10^{-12}	0.49	0.05	10	6	16
25% Fly ash + 25% slag	8.87×10^{-12}	0.54	0.05	11.9	6	17.9
25% Slag + 10% Silica fume	1.7×10^{-12}	0.4	0.05	30.5	6	36.5
30% Fly ash + 10% Silica fume	1.74×10^{-12}	0.4	0.05	23.4	6	29.4

COMPRESSION TEST ANALYSIS

7.1 COMPRESSIVE STRENGTH TEST

Compression test is done to check the compressive strength of the specimen at 28 days, here we have checked the strength at 20 days due to time constraints. Specimen containing 100% OPC showed the highest compressive strength followed by fly ash + silica fume specimen.

7.1.1 100% OPC (20 days)

Using ordinary Portland cement 43 grade which was used to make M30 concrete, during the mixing process, the slump was about 55mm, the compressive strength at 20 days was about 30 $^{N}/_{mm^2}$. This was the highest among the SCM combinations used. When only OPC is used the rate of hydration is quick and the concrete attains more than 90% of its strength by 20 days

Table 7.1

Cube No.	Weight (kg)	Ultimate load (kN)	Compressive strength ($\frac{N}{mm^2}$)
1	7.9	680	30.22
2	8.0	660	29.33
3	8.150	660	29.33

Average compressive strength = 29.62 $^{N}/_{mm^2}$

7.1.2 50% FLY ASH (20 DAYS)

It was observed that while doing the mixing of concrete, fly ash reduced the slump by 30mm, the compressive strength at 20 days was found out to be 9 $^{N}/_{mm^2}$. Referencing other papers, they have similar findings, they have replaced cement by 30% and the 20 day strength is found to be 15 $^{N}/_{mm^2}$. Having 50% replaced is not recommended as the strength is greatly decreased.

Table 7.2

Cube No.	Weight (kg)	Ultimate load (kN)	Compressive strength ($\frac{N}{mm^2}$)
1	7.540	200	8.88
2	7.640	210	9.33
3	7.580	190	8.44

Average compressive strength = 9 $N/_{mm^2}$

7.1.3 50% SLAG (20 DAYS)

It was observed that while doing mixing of concrete, Slag increased the slump by more than 150mm, the compressive strength at 20 days was found out to be 8.14 $N/_{mm^2}$. Referencing other papers, they have similar findings, they have replaced cement by 30% and 20 days strength was about 17 $N/_{mm^2}$. In conclusion we can say that more the slag content, less will be the compressive strength as compared to OPC.

Table 7.3

Cube No.	Weight (kg)	Ultimate load (kN)	Compressive strength ($\frac{N}{mm^2}$)
1	7.305	170	7.55
2	7.330	180	8
3	7.695	200	8.88

Average compressive strength = 8.14 $N/_{mm^2}$

7.1.4 25% SLAG + 25% FLY ASH (20 days)

During mix design, it was observed that due the slag content in the mix the workability of the mix was increased substantially. The slump was above 150mm. The 20 days compressive strength was about 7.4 $N/_{mm^2}$. Referencing other papers, we can see that when fly ash is used in concrete, due to slower rate of hydration, the strength at 28 days is lower than usual, but by 90 days strength increases, now for slag, it also decreases the strength which is proportional to the amount of slag added. In conclusion we can say that due to the material properties of both fly ash and slag, the strength at 20 days is lower and strength at 28 days will also be lower when compared to OPC.

Table 7.4

Cube No.	**Weight (kg)**	**Ultimate load (kN)**	**Compressive strength ($\frac{N}{mm^2}$)**
1	7.360	190	8.4
2	7.545	150	6.66
3	7.8	160	7.11

Average compressive strength = 7.4 $N/_{mm^2}$

7.1.5 25% SLAG + 10% SILICA FUME (20 days)

It was observed that while doing mixing of concrete, the slump was about 30mm, it had reduced by 20mm. the 20 day strength was found out to be 17.33$N/_{mm^2}$. Referencing other papers, we can conclude that slag decreases the strength whereas silica fume slightly increases the strength, the combining effect of the two has given this result at 20 days, which is still lower than normal concrete. It can be concluded that the strength at 28 days will still be lower than normal concrete

Table 7.5

Cube No.	**Weight (kg)**	**Ultimate load (kN)**	**Compressive strength ($\frac{N}{mm^2}$)**
1	8.115	390	17.33
2	7.885	400	17.77
3	7.915	380	16.88

Average compressive strength = 17.33 $N/_{mm^2}$

7.1.6 30% FLY ASH + 10% SILICA FUME (10 days)

It was observed that while doing the mixing of concrete, the slump was reduced by 20 mm. the 10 day strength was found out to be 15.18 $N/_{mm^2}$. This shows that due the mineral properties of silica fume, the strength is slightly reduced. The 28 day strength will only be slightly reduced as we can infer from the data. thus this combination is suitable for construction purposes and also for durability purposes.

Table 7.6

Cube No.	**Weight (kg)**	**Ultimate load (kN)**	**Compressive strength** $\left(\frac{N}{mm^2}\right)$
1	7.690	330	14.66
2	7.72	355	15.77
3	7.615	340	15.11

Average compressive strength = 15.18 $N/_{mm^2}$

CONCLUSIONS

From the above experiments conducted we can come to the conclusion that the most preferred combination of SCM’s to be used for durability purposes would be Fly ash + Silica fume. The material and chemical properties of the materials used assure the durability of the concrete as the pores are filled with fine material. Also silica fume enhances the strength of the concrete, Fly ash enhances the strength but it takes time for hydration , both these materials when used together provide enhanced strength and also enhanced durability. The best combination was at 30% Fly ash and 10% Silica fume which gave around 30 years of service life.

The compression test done on the specimen at 10 days showed strength of 15 $N/_{mm^2}$. This is in accordance with the strength gain by 28 days, it will be more or less similar to OPC. Silica Fume enhances the strength which is proportional to the quantity used. While Fly ash delays the hydration of concrete, it is observed that silica fume counter acts that process and hydration is similar as compared with OPC , thus giving equal strength.

Rapid chloride penetration test (RCPT)

In order to determine the chloride diffusion coefficient at 28 days, a RCPT is done on specimens of dimension 100mm dia and 50mm height. Due to time constraints, the specimens were first placed in accelerated curing tank for 3 ½ hours, then after 24 hours, RCPT was commenced. The results showed that the specimens had not properly cured and the test was cancelled. It is therefore recommended to not perform accelerated curing before RCPT. Also as per ASTM 1202, specimens containing SCM’s have to be cured for 56 days before they can be tested.

CONCL RCPT APPARATUS **’O’s AND PSO’s**

Programme outcomes

No.	Programme outcome	Remarks
1	**Engineering knowledge**: Apply the knowledge of mathematics, science, engineering fundamentals and an engineering specialization to the solution of complex engineering problems.	**3**
2	**Problem analysis:** Identify, formulate, review research literature and analyse complex engineering problems reaching substantiated conclusions using first principles of mathematics, natural sciences and engineering sciences.	**3**
3	**Design/development of solutions:** Design solutions for complex engineering problems and design system components or processes that meet the specified needs with appropriate consideration for the public health and safety and the cultural, societal and environmental considerations.	**2**
4	**Conduct investigations of complex problems:** Use research based knowledge and research methods including design of experiments, analysis and interpretation of data and synthesis of the information to provide valid conclusions.	**2**
5	**Modern tool usage:** Create, select and apply appropriate techniques, resources and modern engineering and IT tools including prediction and modelling to complex engineering activities with an understanding of the limitations.	**3**
6	**The engineer and society:** Apply reasoning informed by the contextual knowledge to assess societal health, safety, legal and cultural issues and the consequent responsibilities relevant to the professional engineering practice.	**2**
7	**Environment and sustainability:** Understand the impact of the professional engineering solutions in societal and environmental contexts and demonstrate the knowledge of and need for sustainable development.	**2**
8	**Ethics :**Apply ethical principles and commit to professional ethics and responsibilities and norms of the engineering practice.	**3**
9	**Individual and team work:** Function effectively as an individual and as a member or leader in diverse teams and in multidisciplinary settings.	**3**
10	**Communication:** Communicate effectively on complex engineering activities with the engineering community and with society at large, such as being able to comprehend and write effective reports and design documentation, make effective presentations and give and receive clear instructions.	**3**

11	**Project management and finance:** Demonstrate knowledge and understanding of the engineering and management principles and apply these to one's own work, as a member and leader in a team to manage projects and in multidisciplinary environments.	**3**

Programme Specific Outcomes (PSO):

No.	Programme Specific Outcomes	Remarks
1	**PSO1:** Identify the field problems, formulate, adopt codal provisions and design Civil engineering structures	**3**
2	**PSO2:** Identify and utilize the latest Materials and technologies, contributing to sustainable, energy efficient and environmental friendly construction.	**3**

REFERENCES

1. Ki Yong Ann, Chloride threshold level for corrosion of steel in concrete, Journal of Corrosion Science, Volume 49, June 2007, pp 4113 – 4133.
2. Chaunqing Fu, Chloride resistance and binding capacity of cementitious materials containing high volumes of Fly ash and Slag, Magazine of concrete research, ICE publishing, 2019
3. Prinya Chindraprasit, Effect of Fly Ash fineness on compressive strength and pore size of blended cement paste, Journal of cement and concrete composites. Volume 27, July 2005, pp 425 – 428.
4. R.B Holland, Effect of different concrete materials on the corrosion of the embedded reinforcing steel, Corrosion of steel in concrete structures, Volume 16, February 2016, pp 131 – 147.
5. J.J Brooks, Influence of supplementary cementitious materials on engineering properties of high strength concrete, Journal of construction and building materials, Volume 25, January 2011, pp 2639 – 2648.
6. Martin Perez, A study of the effect of chloride binding on service life predictions, journal of cement and concrete research, Volume 30, June 2000, pp 1215 – 1223.
7. Radhakrishna G. Pillai, Service life and life cycle assessment of reinforced concrete systems with limestone calcined clay cement, Journal of cement and concrete research, Volume 118, pp 111 – 119.
8. Sripriya Rengaraju, Service life and life cycle assessment of reinforced Concrete with Fly Ash and limestone Calcined Clay Cement, Sixth international conference on Durability of concrete structures, July 2018.
9. Niall Holmes, State of the art review of cathodic protection for reinforced concrete structures, Magazine of concrete research, Volume 68, 2016.
10. Deepak K. Kamde, Corrosion initiation mechanisms and service life estimation of concrete systems with fusion bonded epoxy coated steel exposed to chlorides, Journal of Construction and building Materials, Volume 277, pp 122 – 138.
11. Chien Kuo Chiu, Optimal Maintenance plan for RC members by minimizing life cycle cost including deterioration risk due to carbonation, Journal of Advanced Concrete technology, Volume 6, pp 469-480
12. Afzal Basha, Compressive strength of Fly Ash based cement concrete, International Journal of Innovations in engineering and technology, Volume 4, pp 141- 157.
13. Atul Dubey, Effect of blast furnace slag powder on compressive strength of concrete, International Journal of Scientific and engineering Research, Volume 3, August 2012, pp 100 – 105
14. Muneeb Qureshi, Effects of silica fume on the strength and durability Properties of concrete, CESDOC 2016.
15. Rob. B. polder, Service life and life cycle cost modelling of cathodic protection systems for concrete structures, Cement and concrete composites, May 2013.

BIBLIOGRAPHY

1. IS 8112 "Specification for 43 grade Ordinary Portland cement"
2. IS 383 – 1970 "Specification for coarse and fine aggregates from natural sources for concrete"
3. IS 456 – 2000 "Plain and reinforced concrete – code of practice"
4. IS 516 – 1959 "Test for compressive strength of concrete"
5. IS 2386 "Specifications for method of test of Aggregates"
6. IS 3812 Pulverised fuel ash specifications
7. IS 10262 – 1982 "Recommended guidelines for concrete mix design"
8. IS 2720 part 3 "Specification for test of specific gravity of cement"
9. IS 1727 "Specification for specific gravity test on Fly ash"
10. IS 12089 – 1987 "Specification for specific gravity test on GGBFS"
11. IS IS15388-2007 "Specification for specific gravity test on Silica fume"

PHOTO GALLERY

Fig. 1 Silica Fume bag

Fig. 2 Silica fume powder

Fig. 3 43 Grade cement bag

Fig.5 Fly Ash

Fig. 6 100% OPC cubes

Fig.7 25% Fly ash + 25% slag

Fig.8 25% Slag + 10% Silica fume

Fig.9 50% Slag

Fig.10 50% Fly ash

Fig.11 50mm Slump for 100% OPC

Fig.12 20mm slump for 50% Fly ash

Fig.13 Shear collapse for 50% Slag

Fig.14 Shear collapse for 25% slag + 25% fly ash

Fig.15 30mm slump for 25% slag + 10% Silica fume

Fig.16 Compressive strength test on cubes

Fig.17 Universal testing Machine

Fig.18 Accelerated curing tank

Fig.19 Concrete cylinders cast for Rapid Chloride Penetration Test

Fig.20 Rapid Chloride Penetration Test Apparatus