Service life Prediction of RC Structure Incorporated with GGBS with Respect to Chloride Ions Penetration

G. Priyatham Reddy, B.Kameswara Rao

ABSTRACT: Service-life prediction of reinforced concrete has been extensively studied in the past two decades. It is seen that RC structures have expected to have life more than 100 plus years with effortless maintenance in spite of reinforced concrete structures getting exposed to harsh environments To achieve this objective, durability of structures are required to be produced. To do this, a durable structure needs to be produced.In this work ground granulated blast furnace slag(GGBS) is added to concrete at different levels of replacement. GGBS is replaced in cement at the rate of 50 %, 60 % and 70 % and its strength and chloride penetration of concrete is determined. Chloride ingress is a critical attack of environment on concrete structure, which corrodes the steel reinforcement and thereby reduce the strength, serviceability and aesthetics of the structure. This is the basic reason for frequent repair and early replacement of structure. To prevent deterioration due to chorine penetration is using concrete which are resistant to chloride attack. This is possible by understanding the ability of chlorine ion penetration in the concrete at the design, production and quality control cycle. Chloride ion penetration is a slow process and cannot be determined in specific time frame to set standards of quality before it is put to use. To predict the service life and to asses chlorine penetration, accelerated test procedure and predictive model is required to determine the value of chlorine diffusion in specified period of time.

KEYWORDS: Service life Prediction, GGBS, Chloride ion penetration

I. INTRODUCTION

The period of usage of a product or building structure is defined as servicelife is defined. It is also defined as a total life the product is serving its purpose and is in use from the point of construction to the point of discarding. Terminology of Serviceability as per civil engineers refers to the condition under which a building is under useful condition and it is the period till which the building is structurally sound would nevertheless to be considered unfit. The serviceability limit is influenced by various factors like corrosion, cracking and excessive vibration.

Service life of RC structure is defined as a reliable prediction of service is dependent on the corrosion state of RC structures. A reasonable and accurate servicelife prediction will enable the construction fraternity to take necessary preventive measures on time, avoid unnecessary cost to repair and rework can lead to disastrous situation if no precautionary measures taken. Few factors make the service life prediction little difficult (a) Unpredictable environmental parameters (b) Time based variation. Even though science has taken us very close to the understanding the deterioration process, one of the strong influencer is the corrosion if reinforcement. Reinforcement are highly alkaline and corrosion induced deterioration so researchers have arrived at a conclusion that corrosion of reinforcement has to be critically determined which will enable service life prediction of reinforced concrete structure..

A.Ground Granulated blast furnace slag (GGBS):

GGBS is hydraulic binder which will bring about improvement in quality and durability of concrete. GGBS production is literally free form carbon dioxide blast furnace produce pig iron which leads to a product called "slag", it is lightly controlled and stable material and has some constituents of normal cement. If the slag is vitrified (glass like substance) by rapid quenching at a point of exist of the blast furnace,it is cementations quality can be preserved. It is then dried and ground as a fine powder.GGBS is often used as replacement from 30 to 70 % in ordinary cement.

B. Chemical composition of GGBS:-

Raw materials used in iron production process is an influential factor to bring modification in the chemical composition of slag. Viscosity of the slag gets lowered when impurities of silicates and aluminates of ore and coke are mixed with flux in the blast furnace. Limestone and forterage and rarely dolomite form the constituents of flux in pig iron products. Slag floats on surface of iron in case of blast furnace and it is separated by decantation.

C. Typical chemical composition

Calcium oxide	- 40 %
Slica	-35%
Alumina	-13%
Magnesia	-8%

Ideal glass content which will blend with Portland cement is from 90 to 100 %, which is depended on the method and initial temperature of cooling. The structure of quenched glass is dependent on the proportionality of Si, Al and other network modifying elements like Ca, Mg..

Typical Chemical Composition:

Color - off white, Sp.gravity-2.9

Bulk Density-1200 kg/m3, Fineness-350 m2/kg

D. Concretes containing ground granulated blastfurnace slag (GGBS)

Revised Manuscript Received on April 15, 2019.

G. Priyatham Reddy, research scholar, KoneruLakshmaiah Education Foundation (Deemed to be University), Green fields, Vaddeswaram, A.P., India

Dr.B.Kameswara Rao, Professor, Department of Civil Engineering,KoneruLakshmaiah Education Foundation (Deemed to be University), Green fields, Vaddeswaram, A.P., India

*Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication*

Pig iron and slag production happens simultaneously and control is established to ensure less variation in both. Next stage is for slag granulation or pelletisation. In this stage the slag which is granulated is ground to make it finer particles , which is more than 350m^2/kg. This particle is expected to be finer than Portlandcement. Fine particles will increase the working at early stage. In few cases GGBS which is more than 500m^2/kg is used. Incorporating GGBS in concrete mix brings benefits , few of which are listed below:-

- Lower peak temperature as heat development is slow.
- Durability and strength is improved due to density of the microstructure of hydrated paste of cement.
- Irrespective of alkali present in OPC and its reactivity factor, its risk due to alkali-silica reaction can be eliminated

E. Influence of GGBS on properties of fresh concrete

GGBS in the mix improves workability and mix becomes mobile though cohesive in nature. This is contribution due to the dispersion of cementations particles and GGBS surface character of being smooth and absorbing water. Very fine GGBS brings about reduction in bleeding of concrete. GGBS mix can cause early loss of slump. Retardation can happen at normal temperature for 30 to 60 minutes if GGBS in present in the mix.

II. OBJECTIVE:

a) To analyze the performance of OPC cement partially replacing it with GGBS.
b) To examine the level of deterioration in the concrete structure due to chloride penetration in the partially replaced concrete.
c) To predict a model for early detection of chlorine ion ingress to have control during design , production and quality control stages.

III. SCOPE

The work is planned to be carried out using GGBS as partial replacement to OPC. The chloride penetration test as per ASTM standards are planned to be done on 24 blocks varying the percentage of GGBS in OPC. Predictive model is planned for early detection.

IV. BENEFITS OF USING GGBS IN CONCRETE

A. Sustainability

Reports say manufacturing one ton of portland cement consumes 1.5 tons of minerals which needs to be extracted spending 5000 MJ of energy. This process would create 0.95 ton of carbon di oxide. Reports gives a comparison of using GGBS, which is a byproduct obtained from iron industry. As per the report, one ton of GGBS production will lead to only about 0.7 tons of CO2 equivalent consuming only 1300 MJ of energy. .

B. Setting Time

Concrete setting time is important aspect which is dependent on factors like water/cement ratio at a particular temperature. Setting time is expected to be more by 30 minutes with GGBS being used. Concrete will have longer working life with less number of joints with extended setting time, which is visible more in warm weather.

C. Durability aspects of concrete containing GGBS

GGBS mortar shows reduction in permeability of water by factor up to 100. Chlorine ion diffusion is also largely reduced in the mortar of GGBS. Resistance to penetration of chloride ions is found to be good in GGBS concrete. It is experimentally by Daubed and Bakker that diffusion coefficient of concrete with GGBS having exposure to chloride ions is ten times lesser than pure OPC.

D. Mechanisms involved in concrete deterioration by corrosion embedded steel:

Steel corrosion is an electro chemical process and it has potential to generate corrosion cells in the surface vicinity of reinforcing steels. Its concentration is due to variation in the dissolved ion concentration say for example alkalis and chlorides. This process makes one part of metal anodic and other part cathodic. The chemical reaction at anode and cathode will be as follows: -

Anode: Fe --------> 2e $^-$ + 2 e $^{2+}$
(Metallic iron)

Cathode: 1/2 O_2+H_2O+2e^- --------> 2$(OH)^-$
(air) (water)

When metal ion changes to rust , there will be increasing volume based on the oxidation stage. The volume can go up to 600 percent of the original metal. Volume increase is the primary reason for concrete to expand and crack. Crystalline ion hydroxide will imbibe water and expand like ettrinigite. Metallic ion will not get ironized much till the electron start to flow to cathode. This is controlled by the electron consumption at cathode which is essential. Steel when gets embedded in concrete, there is a formation of protective passive film on the surface.The pores of cement paste will have alkaline condition and heavy concentration of hydoxides are formed in an environment with a PH from 12 and 14. There will be double layer of oxide film which has an inner iron II layer (mainly Fe_3O_4) and an outer iron (III) oxide layer (mainlyγ-Fe_2O_3). This shows that metal ion is not available to have anodic reaction till the stage of destruction of passivity of steel. The protective layer gets destroyed at PH above 11.5 when CHO/H^- is molar . This happens in the presence of chloride ion depending on CH/OH^- ratio.

If the ratio goes above 0.6 , steel will no longer be able resist corrosion due to the film of iron oxide which is either permeable or unstable. It is preferred to have initiation of corrosion in the order of 0.4 percent of the cement content. This is critical and it is dependent on .

1. Degree of Carbonation
2. Concrete Quality
3. Relative humidity

Once the passivity of the steel which is embedded is destroyed at one point. Then the electrical resistivity and availability of oxygen become the controlling the corrosion rate. The common sources of chloride in concrete are admixtures,salt-contaminated aggregate and penetration of deicing salt solutions or seawater.

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

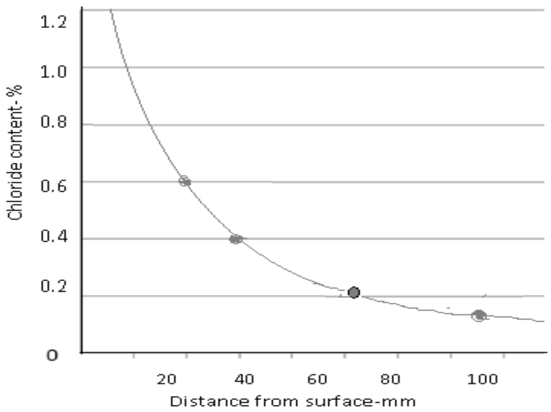
E. Chlorides in the mix

Incorporation of contaminant, aggregates or sea water or brackish water or any other admixtures can bring the presence of chlorides in concrete. The BS 8110-1:1997 states that total chloride ion content in a concrete which is reinforced will have to be 0.4 % by mass of cement. ACI 310-02 considers only water dissolving chloride ion. Adhering to this standard the content of chloride ion in the reinforced concrete is expected to 0.15 % of the mass of cement. Determination of acid-soluble chloride content is determined as per ASTM C 1152-04 or BS 1881-124:1988.Potentiometric titration is expected to give high value of chloride content due to existence of some admixtures. There are variety of techniques for determining the chloride content which are water soluble..

F. Ingress of chlorides

Sea water can get in touch with concrete which is source of chloride ingress. Chlorides deposition occurs on the concrete surface carried by air or droplets of seawater carried by air or dust wetted later by dew. Reports say air borne chlorides can travel substantially up to a distance of 2 km which depends on the wind and topography. Movement of Air borne salts gets affected by the configuration of building. Eddies in air will make the salt reach structure which are facing landward. Irrespective of the external origin, chlorides have their path to building by transportation of water with chloride content and by absorption. Chloride ion ingress can be prolonging and repetitive. With time there will be high concentration of chloride ions at the surface of the reinforcing steel in concrete. It is be noted that chloride ingress is progressive in nature.

There is a tendency for the dry concrete to absorb salt water under certain conditions. This will continue. Under appropriate external condition, the water can evaporate into the air by capillary action through the pores. However it is to be noted the pure water evaporates leaving the salt on the surface, there by increasing the concentration of salt on the surface of concrete. This creates concentration gradient, due to which the salts near the surface of the concrete will diffuse in inward direction which is zone of lower concentration. Diffusion is depended on external humidity and the time duration for drying. In most cases, the water in the outer zone evaporate and the balance diffuse inside which saturates and excess of it precipitates to form crystals. In net effect, the water moves out and salts stays back. Further wetting can happen in next stage which will bring more salt present in the capillary pores. The gradient of concentration will decrease outward from a peak value at some depth. Now the salts may diffuse outside on the surface of concrete. This cycle will continue to happen over a period of time. The exact extend of salt movement is based on the length of the wetting and drying period. There will be rapid wetting period and slow drying cycle. The interior of concrete will never dry and ion diffusion is very slow during the wet period. Progressive ingress of salt takes place alternatively during the wetting and drying period. The figure shows profiling of chloride established based on the chemical analysis of the sample of dust by reaching various depths from surface by means of drilling. On exposing the concrete up to a period of 10 years, the chloride ion content can be more than the concentration of sea water. In span of few years, sufficient amount of chloride particles will reach the surface of the concrete.



V. TESTING OF GGBS CONCRETE:

A. Micro structure:-

The permeability of GGBS concrete is less and it is chemically stable when compared with ordinary cement. This improves consistency in many ways of deleterious attack.

a) Disintegration due toSulphate attack.
b) Corrosion due to chloride attack.
c) Cracking caused by Alkali-silica reaction.

B. Corrosion of reinforcement by chloride

The steel which are embeded in the concrete gets its protection against corrosion due to the alkalinity created inside the concrete due to cement hydration. There will be passive layer formed on the steel surface and this inhibits rusting. The ability of significant chloride to penetrate can destroy the steel embedded by rusting and corrosion. GGBS can be of substantial support because of the fine pore structure making the concrete more resistant to diffusion of chloride than OPC.GGBS reinforced concrete will improve the durability thereby making it useful in highway structures subject to deicing salts and in coastal atmosphere. Higher the GGBS percentage better will be its resistance to chloride penetration. The percentage will vary from 50 to 70 percent.

C. Chloride Penetration tests:

1. Resistance to chloride ion penetration or the salt pounding test.
2. Test for bulk diffusion (modest NT Build 443)
3. AASHTOT277: Rapid chloride penetration test. It displays electrically the ability of the concrete to resist chloride ion penetration.
4. Technique of electric migration
5. Test of rapid migration (CTH test)
6. Technique to check resistivity
7. Technique to check pressure penetration
8. Technique of indirect measurement
9. Sorptivity

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

VI. CONCLUSION:

The proposal to replace cement with 50 %, 60 % and 70 % of GGBS for obtaining the service life prediction due to chloride penetration. It is expected to elaborate the details of structural and environmental parameters which would get deteriorated due to corrosion. It is also planned to have testing done in the lab to identify causes of corrosion over a period of time. This model is expected to overcome the problem of early replacement of concrete structure and gives the prediction to design right at the time and also have control on quality during the production. The test method proposed accelerates the process and would allow the determination of diffusion values in appropriate time .

REFERENCE:

1. K.D. Stanish, R.D. Hooton and M.D.A. Thomas, Testing the Chloride Penetration Resistance Of Concrete: A Literature Review, 2011.
2. Sanjeev Kumar Verma,1 Sudhir Singh Bhadauria, Probabilistic Evaluation of Service Life for Reinforced Concrete Structures, Hindawi Publishing Corporation,2014.
3. W.-M. Zhang and H.-J. Ba, “Accelerated life test of concrete in Chloride environment,” Journal of Materials in Civil Engineering, vol. 23, no. 3, pp. 330–334, 2011.
4. W. Chai, W. Li, and H. Ba, “Experimental study on predicting Service life of concrete in the marine environment,” Open Civil Engineering Journal, vol. 5, no. 1, pp. 93–99, 2011.
5. D. Vorechovska, B. Teply, andM.Chroma, “Probabilistic assessment of concrete structure durability under reinforcementCorrosion,” Journal of Performance of Constructed Facilities, vol.24, no. 6, pp. 571–579, 2010.
6. L. Parameswaran, R. Kumar, and G. K. Sahu, “Effect of carbonationOn concrete bridge service life,” Journal of BridgeEngineering, vol. 13, no. 1, pp. 75–82, 2008.
7. S. Rostam, “Service life design of concrete structures: a challengeTo designers as well as owners,” Asian Journal of CivilEngineering, vol. 6, no. 5, pp. 423–445, 2005.
8. B.Martin-Perez and Z. Lounis, “Numerical modeling of servicelife of reinforced concrete structures,” in Proceedings of the 2ndInternational RILEM Workshop on Life Prediction and AgingManagement of Concrete Structures, pp. 71–79, Paris, France, May 2003.
9. A. Abu-Tair, C. McParland, J. F. Lyness, and A. Nadjai, “PredictiveModels of deterioration rates of concrete bridges using theFactormethod based on historic inspection data,” in ProceedingsOf the 9th Durability of Building Materials and Components(DBMC ’02), pp. 2621–2629, Brisban, Australia, 2002.
10. B. Teply, “Modeling of deterioration effects on concrete structures,”ActaPolymerica, vol. 42, no. 3, pp. 8–12, 2002.
11. A. D. Orcesi and D. M. Frangopol, “Use of lifetime functionsin the optimization of nondestructive inspection strategies forbridges,” Journal of Structural Engineering, vol. 137, no. 4, pp.531–539, 2011.
12. S MAHIMA1, P V P MOORTHI2, Influence of chloride threshold value in service life predictionOf reinforced concrete structures, 2012
13. Al Hashem A 2011 Corrosion in the gulf cooperationcouncil (GCC) states: statistics and figures. In: ProceedingsOf Corrosion UAE, Abu Dhabi, UAE
14. Tang L and Lars-Olof N 1992 Rapid Determination of thechloride diffusivity in concrete by applying an electricalField. ACI Materials Journal 89(1): 49–53
15. McGrath P F and Hooton R D 1996 Influence of voltage onchloride diffusion coefficients from chloride migrationtests. Cement and Concrete Research 26(8): 1239–1244,https://doi.org/10.1016/0008-8846(96)00094-4.
16. Reddy, M.M., Reddy, K.R.S., Asadi, S.S., 2018. A study on compressive strength of conventional concrete by replacing with flyash and sugarcane ash. *International Journal of Pure and Applied Mathematics*, 119 (14), pp. 1787-1791.
17. Kumar, B.S.C. and Ramesh, K., 2016. Experimental study on strength properties of metakaolin and GGBS based geopolymer concrete. *ARPN Journal of Engineering and Applied Sciences*, *11*, p.21.

AUTHORS PROFILE

G. Priyatham Reddy has a bachelors degree in Civil Engineering and has done my Masters in Structural Engineering SRM University. I am pursuing my research in concrete technology as a PhD Scholar in KLE University under the guidance of Mr. Dr B KameswaraRao. As a part of his research author has taken up study on “Servicelife prediction of RC structure incorporated with GGBS with respect to chloride ion penetration”.

Dr B KameswaraRao working as a Professor in Civil Engineering Department, KLUniversity, Vaddeswaram,Vijayawada, India.He is a Civil Engineer with Structural Engineering as specialization. He worked as Scientist 'G', Structural Engineering Division, Central Building Research Institute, Roorkee, Uttarakhand State, India.

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication