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A Study of Develop a Service Life Estimation Process System towards Reinforced Concrete Cement (RCC)

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ABSTRACT

This study aims to formulate a method to determine the service life estimation of Reinforced Cement Concrete structures based on the experimental data generated by conducting various durability tests using different grades of concrete with and without mineral and chemical admixtures. The scope of the work involves studying the durability properties such as chloride diffusion, Rapid Chloride Penetration Test, Water Permeability, Resistivity and Accelerated corrosion test for different grades of concretes with and without mineral admixtures to formulate a relationship among the durability parameters for estimating the service life of reinforced concrete. The Concrete is the most versatile and unique material for building industry. The outcome of the research work carried out by various researches indicates that the service life of the reinforced cement concrete structures can be extended in many ways viz., the use of higher strength concrete, higher concrete cover thickness, use of mineral and chemical admixtures, applying epoxy like coating over the steel and concrete surface, use of corrosion inhibitors, anodic and cathodic protection techniques, etc. Based on this experimental results and co-relationship between durability properties, a model has been developed using MATLAB program to estimate the service life of reinforced concrete structure. The model has been validated with the experimental results carryout on concretes especially for validation and found very good. This study also covers the effect of concrete cover thickness, concrete surface coatings, corrosion resistance steel and corrosion inhibitors on durability. From the results of durability study, the constitutional relationship among RCPT, Chloride Diffusion, Water Permeability, Resistivity and Accelerated Corrosion Initiation Time has been formulated. From this co-relation, an equation has been obtained which helps to estimate the service life of reinforced cement concrete structures made with materials of similar to what has been used in the study.

1. Introduction

During the past several decades, concrete structures had suffered from safety and serviceability problems due to deterioration of concrete. Generally concrete is a very durable material, the environmental factors such as weathering action, chemical attack, abrasion and other deterioration process may change the properties of concrete with time when rebar is embedded into the concrete. The deterioration of Reinforced Cement Concrete (RCC) Structures is due to the corrosion of steel used in concrete. Corrosion of reinforcing steel results in the build-up of voluminous corrosion products generates internal stresses which lead to cracking and spelling of the cover concrete. The main causes of rebar corrosion are due to ingress of chloride ions or diffusion of CO2 gas from atmosphere. A lowering of the pH by penetration of free chloride ions though the concrete cover to the steel, or by the carbonation of the concrete cover due to penetration of atmospheric carbon dioxide, can cause breakdown of the passive layer.

In general, good quality concrete provides an excellent protection for steel reinforcement. The steel used in concrete are remains in passive state due to high alkalinity of concrete. The time to initiate corrosion is determined largely by the amount and the quality of concrete, cover thickness as well as permeability of concrete. Once de-passivation occurs, corrosion propagation is governed by anodic, cathodic and/or electrolytic properties of corrosion cell. The rate of chloride diffusion is influence in concrete with w/b, ratio and the properties of paste such as type of cement, mix ratio and percentage of supplementary cementing material, temperature and humidity. The corrosion of steel in concrete lead to repair and rehabilitation which causes incredible cost. There is an increasing amount of research being performed to investigate method of corrosion prevention, or to minimize corrosion damage where it has already begun. There is an obvious need to improve the product, but inevitably there will also be a perpetual need for repair and rehabilitation. The service life of rebar in concrete can be enhanced by various protection method such as, providing larger cover thickness, better quality concrete by using mineral and chemical admixtures, coating to steel, addition of corrosion inhibitors in concrete, cathodic protection and barrier coating to steel and concrete surface. Each method has its own advantages and disadvantages. Extensive research has been carried out in the field of rebar corrosion in RCC members.

2. Review of literature

The concrete should with stand the process of deterioration for which it is expected to be exposed. The life cycle cost of the buildings is increasing due to corrosion prone aggressive environment and become difficult to manage. To meet the technical and economic concerns, efforts are being made to enhance the service life of concrete structures by various methods. This chapter reviews the number papers published by various researchers studied on concrete durability with regard to High strength and High performance concrete, chemical corrosion inhibitors, protective coatings on steel reinforcement (e.g. epoxy-coated or galvanized steel),corrosion resistant steel (e.g. stainless steel), non-ferrous reinforcement (e.g. fiber reinforced plastics), waterproofing membranes or sealants applied to the exposed surface of the concrete, cathodic protection and combinations of the above. Experimental test method such as chloride permeability, chloride diffusion, accelerated corrosion test, resistivity, Half-cell potential tests carried out to evaluate the durability properties of concrete by various researchers are reported. A number of models for predicting the service life of concrete structures exposed to chloride environments or for estimating lifecycle costs of different corrosion protection strategies have been developed recently are also discussed. The approaches adopted by the different models vary considerably and service life prediction model for reinforced concrete structures are modeled.

High Performance Concrete (HPC) provides a solution, and achieves a specified service life by enhancing the concrete characteristics such as volume stability, long term mechanical properties in terms of durability, etc. Blending cement with Supplementary Cementitious Material (SCM) such as fly ash and GGBS will help in producing the concrete with a dense microstructure, which will improve the impermeability of concrete against chloride ion penetration. The impermeability of concrete can be represented by the rate of flow of chloride ions though a unit area of concrete. This flow rate or diffusion Co-efficient was measured by various laboratory test method (Gjorv1996). Apart from the concrete strength characteristics, performance of such concrete is very much important on durability aspects. A good quality concrete should serve the demand for which it is designed. Therefore, we need a tool to indentify a suitable concrete to perform in different environmental conditions. The service life prediction of the reinforced concrete structure is based on the time to initiate corrosion of steel. The time at which corrosion is initiated and the rate at which it proceed are dependent upon the rate of chloride ions diffusion though the concrete, and hence, highly dependent upon the concrete itself. Several research works have been carried out to improve the concrete quality by the use of mineral and chemical admixtures in concrete, and there performance has been studied with respect to strength and durability. Also, the use of increased concrete cover thickness, epoxy coating over concrete surface, use of corrosion inhibitors in concrete were studied to enhance the service life of concrete structures. All these studies can give an idea about the use of several methods to improve the concrete quality. But, there is no tool available to select a suitable concrete type to meet the functional requirement.

An attempt has been made in this study to develop a tool for service life estimation of reinforced concrete structure particularly induced by chloride ions. The main focus is limited only to chloride ion ingress, since, India is mostly surrounded and exposed by sea shore and the most of the building structures are affected by chloride attack. This tool will also give the user to select suitable concrete types which can meet the functional need. This tool has been developed by studying the durability properties such as chloride diffusion, RCPT, permeability, resistivity and corrosion initiation time of different types and grades of concretes with and without mineral admixtures. These durability properties were correlated with each other and developed a tool for service life estimation of reinforced concrete structures, particularly with respect to chloride ions ingress.

3. High Strength Concrete

High-strength concrete is often considered a relatively new material. Its development has been gradual over many years, the development has continued and the definition of high-strength concrete has changed. The development of high strength concrete has been discussed by Russell 1997 as follows. In the 1950s, concrete with a compressive strength of 34 MPa was considered as high strength. In the 1960s, concrete with 41 and 52 MPa compressive strengths were used commercially. A book written by Michael A. Caldarone, 2009 on high strength concrete – a practical guide and given details about the development of high strength concrete. In the early 1970s, 62 MPa concrete was being produced. More recently; compressive strengths approaching 138 MPa have been used in cast-in-place buildings. For many years, concrete with compressive strength in excess of 41 MPa was available at only a few locations. However, in recent years, the application of high strength concrete has increased, and high-strength concrete has now been used in many parts of the world. The growth has been possible as a result of recent developments in material technology and a demand for higher-strength concrete.

4. High Performance Concrete

High-performance concrete (HPC) not only have high strength but also have good durability. The high-performance concrete has very low permeability, of which permeability is about 1/100 of the conventional concrete. It is one of the main reasons to use HPC to solve the problem of corrosion of steel (FaguangLeng et al 2000). The resistance to chloride penetration is one of the simplest measures to ensure the durability of concrete. The high-performance concrete may be defined as the concrete having high resistance to chloride penetration as well as high strength. Since high resistance to chloride penetration can be directly related to low permeability that control the deterioration process in concrete structures. This provides a firm basis for the use of high-performance concrete having very low permeability and high durability in the actual structures under severe conditions (Byung Hwan Oh et al 2002). High performance concrete (HPC) is cement-based concrete, which meets special performance requirements with regard to workability, strength, and durability, that cannot always be obtained with techniques and materials adopted for producing conventional cement concrete (Rajamane et al 2003). High Performance Concrete (HPC) provides a solution, and achieves a specified service life by enhancing the concrete characteristics such as volume stability, long term mechanical properties in terms of durability, etc (Kyong Yun Yeau et al 2004). Oner and Akyuz, 2007 has reported that the use of 55% GGBS in total binder content is the optimum point, further addition of GGBS does not improve the compressive strength.

5. Corrosion

Reinforcement corrosion is one of the most common causes for reinforced concrete structures deterioration. Corrosion damage to the reinforcing steel results in the build-up of voluminous corrosion products generating internal stresses and subsequent cracking and spalling of the concrete. The main causes of rebar corrosion are due to ingress of chloride ions and CO2 which destroys the natural passivity of reinforcement located in alkaline concrete condition. In general good quality concrete provides excellent protection for steel reinforcement. Due to high alkalinity of concrete pore fluid, steel in concrete initially and in most cases, for sustained long periods of time, remains in a passive state. Initiation of corrosion occurs either due to reduction in alkalinity arising from the breakdown of the passive layer by the attack of chloride ions. The time to initiate corrosion is determined largely by the amount and the quality of concrete, cover thickness as well as permeability of concrete. Once de-passivation occurs, corrosion propagation is governed by anodic, cathodic and/or electrolytic properties of corrosion cell.

Effect of Chloride Ingress in Concrete

The factors related to declining concrete durability are carbonation, corrosion, alkali-silica reaction, freezing and thawing. The penetration of chloride-ions into concrete has been regarded as the major deterioration problem. Ingress of chloride-ions destroys the natural passivity of the surface of reinforcing steel, and often lead to the corrosion of steel in concrete structures (Kyong Yun Yeau et al 2004). The presence of sulfate ions in chloride environments did not affect the time-to-initiation of reinforcement corrosion. It can be concluded that protecting the ingress of chloride-ions is more useful than preventing the attack of sulfate ions in case of the coexistence of sulfate and chloride-ions. A common method of preventing such deterioration is to prevent chlorides from penetrating the structure to the level of the reinforcing steel bar using relatively impenetrable concrete.

Effect of Cement Type on Concrete Durability

It is confirmed that chloride permeability decreases with increased volume of Supplementary Cementing Material (SCM), but Ordinary Portland Cement itself is more resistant to chloride penetration when compared to special cements such as sulfate-resisting Portland cement. (Byung Hwan Oh et al 2002).

Effect of Aggregate Properties on Concrete Durability

The rate at which chloride ion ingress into saturated concrete occurs depends on the chloride ion diffusion Co-efficient of the concrete's cement paste and aggregate fractions and the aggregate volume concentration (Hobbs 1999). In the limestone concrete, it appears that chlorides can be transported though the aggregate as well as though the surrounding cement paste. Carbonation and water permeability data indicate that the aggregate could play an important role in influencing chloride ingress into concrete (Page et al 2009). The carbonation depths for Portland cement concretes of similar water-cement ratios subjected to sheltered external exposure were on an average of 90% greater for concretes containing a lightmass coarse aggregate (sintered pulverized fuel ash) than for concretes containing dense coarse aggregate. The chloride ion diffusion Co-efficient of the cement paste is dependent on w/c ratio and degree of hydration, but if its diffusion Coefficient is lower than that of the aggregate, then, ignoring interfacial effects, chloride ion ingress will increase with increasing aggregate volume (Hobbs 1999). The effect of maximum size of aggregates on the chloride permeability is a important parameter but not only the maximum aggregate size but the aggregate particle size distribution and aggregate-paste volume ratio also influence on the formation of the microstructure of concrete, (Byung Hwan Oh et al 2002). To achieve a specified working life, controls are necessary both on the quality of concrete's paste fraction and it's aggregate. If the diffusivity of the aggregate and paste fractions is not the same, then chloride ion mass flow and chloride ion concentration gradient are nowhere near uniform across a concrete in the normal direction of diffusion. The chloride ion diffusion Coefficient of the aggregate ranges from 0.20 to 10 times that of a cement paste matrix (Hobbs 1999).

Importance of Water Binder Ratio for a Durable Concrete

The water cement ratio governs the porosity of the hydrated cement paste. The value of water cement ratio was relevant to many aspect of durability (Adam Neville 2000). The chloride ions diffusion Co-efficient increases with increase in w/c ratio. The diffusing paths of chloride ion into concrete have three paths: the interconnected pores in cement paste, the interconnected pores in aggregate, and the interconnected pores in the interfaces between paste and aggregate. When the permeability of aggregate was significantly lower than that of hydrated paste and the interface between aggregate and paste has no apparent deficiencies, the main diffusing path exists in the paste. Thus, the compactness and volume of paste are the two main causes affecting the diffusing velocity of chloride ions (Kyong Yum Yeau and EumKyum Kim 2004).

6. Improvement Of Concrete Durability

Effect of Concrete Cover on Concrete Durability

Insufficient concrete cover or poor quality concrete lead to reinforcement corrosion. Theoretically, bars embedded in concrete structures are protected both chemically and physically against environmental corrosion using concrete cover. The high alkalinity of the pore solution of the concrete cover provides the chemical protection and the impermeability of the concrete cover is expected to provide a physical protection against the ingress of deleterious materials like chloride ions. To control the reinforcement corrosion, the rate of chloride penetration should be minimized. Chloride penetration deeply depended on the depth and quality of concrete cover. The resistance of steel corrosion is superior when the thickness of concrete cover is large but too much a cover could result in larger and more cracks allowing direct access of aggressive agents to the steel reinforcement (Ampadu 1999). The impermeability of concrete depends on the depth of concrete cover, cement type, and Fly ash or GGBS content. The impermeability of concrete cover can be further improved by using high strength and durable concrete such as High Performance Concrete (Kyong Yum Yeau and EumKyum Kim 2004). For a concrete cover of 70 mm, the time necessary for corrosion initiation ranges from 3 to 6 years for the synthetic seawater exposure. The cover depth of 50 mm for 3 years in the synthetic seawater, a concrete cover of at least 90 mm is required for an exposure period of 10 years in the same exposure (Erdogdu et al 2004).

Effect of Cement Replacement Materials on Concrete Durability

A High Performance Concrete using cement alone as a binder requires high paste volumes, which often lead to excessive shinkage and large evolution of heat of hydration, besides increased cost. A partial replacement of cement by mineral admixtures (MA), such as, fly ash, ground granulated blast furnace slag (GGBS) and silica fumes (SF) in concrete mixes overcome these problems and lead to improvement in the durability of concrete and also leads additional benefits in terms of reduction in cost, energy savings, promoting ecological balance and conservation of natural resources, etc. (Rajamane et al 2003). GGBS, obtained as an industrial by-product from iron and steel industry, serves as a supplementary cementitious material (SCM) by forming additional calcium silicate hydrate (C-S-H) gel and thereby increases the denseness of the matrix though pore refinement. Slag hydration is hindered by formation of a protective film on the surface of GGBS particles and activation of hydration will not occur until pH of pore solution exceeds 13.2 and glass fraction of the slag is broken down by hydroxyl ions. This requires a certain amount of hydration of cement to take place. Before the cement hydration, GGBS particles serve as nuclei for precipitation of cement hydration products. At later ages, GGBS acts as an effective cementitious material.

7. Conclusion

An extensive literature survey has been made to review the current knowledge on the service life prediction of reinforced cement concrete structures affected by chloride ions. Literature review also done for the tests method followed by various researchers to study the durability properties of concrete structures and the method followed for service life prediction.Co-relation of durability properties were formulated with each other. The co-relation between the durability properties gives an equation and helps to estimate the service life of reinforced cement concrete structures. Based on this, a software model was developed using MATLAB program to predict the service life. This model has been validated by comparing the output obtained from the model with the experimental results conducted in the laboratory.

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