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Impact of Carbonation in RC Structures

N. Durai Seeni Vasan[1], C. Jayaguru[2]
[1]PG student, Department of Civil Engineering, PSNA College of engineering and technology, Dindigul, Tamilnadu, India
[2]Professor, Department of Civil Engineering, PSNA College of engineering and technology, Dindigul, Tamilnadu, India

ABSTRACT

The Corrosion of reinforcement in concrete has been identified as a major cause of deterioration in reinforced concrete (RC) structures. Carbonation is the one of the factor which affect the durability of concrete and accelerates the corrosion in RC structures. Results from previous studies shows that co2 concentration in the atmosphere was 390ppm in the year 2010. That will increase at 414ppm in the year 2020, the increasing co2 concentration in atmosphere increases carbonation effect in concrete and it leads to reinforcement corrosion in RC structures. Hence adoption of suitable protective measures are essential for exposed RC structures against carbonation induced corrosion. In this study we numerically evaluate the concrete carbonation with different climatic condition using the mathematical software MATLAB and compare these results with the existing models. The results conclude that the Yoon model is relatively nearer to the existing building modelling, Numerical model created in the MATLAB is verified with experimental investigation.

Keywords: Carbonation, MATLAB, Corrosion, Diffusion coefficient.

I. INTRODUCTION

Reinforced concrete is one of the most common materials used by the construction industry all over the world. Reinforced concrete structures are subjected to wide range of exposure conditions including marine, industrial, or other severe environments. High durability requirement is not always achieved in practice due to which corrosion of reinforcement in concrete is one of the main cause of deterioration in RC structures. Reinforcement corrosion has been widely reported and it is one of the main durability problems.

Reinforced concrete is used for construction of infrastructure such as bridges, tunnels and harbor structures. It is also used for offshore platforms and wide range of public and private buildings. Reinforced concrete are subjected to wide range of exposure conditions, including marine, industrial or other severe environments. The functionality and reliability of infrastructure is crucial for society and its economy to function. Concrete normally provides a high degree of protection to the reinforcing steel against corrosion by virtue of the high alkalinity (pH 13.5) of the pore solution. Under high alkalinity steel remains passivized. In addition, well consolidated and cured concrete with low w/c ratio has a low permeability, which minimizes the penetration of corrosion including agents such as chlorides, CO2, moisture etc. to steel surfaces. Further the high electrical resistivity of the concrete restricts the rate of corrosion by reducing the flow of electric current from the anodic to the cathodic sites. At the outset, it must be mentioned that usually in a properly constructed and maintained structure, there should be little problem of corrosion during its service life.

In general there are two major features which cause corrosion of reinforcement in concrete to an unacceptable degree; (i) Carbonation (ii) Presence of chloride ions which may either have been present in the concrete constituents right from the beginning are introduced into the concrete during the service life. When the rebar in the concrete is exposed to the chlorites, either contributed from the concrete ingredients or penetrated from surrounding chloride bearing environment, carbonation of concrete or penetration of acids into the concrete are the causes of reinforcement corrosion along with others related to the external environment such as moisture, oxygen, humidity, temperature and acid attack.

II. MECHANISM OF CORROSION OF REBAR IN CONCRETE

Corrosion of steel embedded in concrete is an electrochemical process. The surface of the corroding steel functions as a mixed electrode that is a composite of the anode and the cathode electrically connected through a body of steel itself upon which coupled with anodic and cathodic reactions take place.

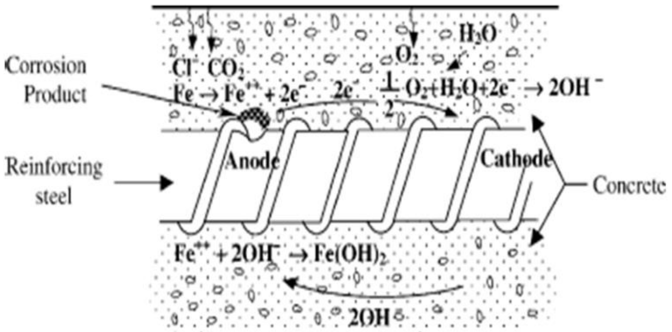

Fig.1 Corrosion of reinforcement steel in concrete

Anodic reaction :

$Fe \rightarrow Fe^{2}++2e-$ Cathodic reaction :

$\frac{1}{2}O2 + H2\ O + 2e- \rightarrow 2OH-$

$Fe2+ + 2OH- \rightarrow Fe(OH)2$ (Ferrous Hydroxide)

$4Fe(OH)2 + 2H2\ O + O2 \rightarrow 4Fe(OH)3$ (Ferric Hydroxide)

$2Fe(OH)3 \rightarrow 2H2\ O + Fe2\ O3 \cdot H2\ O$ (Rust)

Fig.2 Progress of corrosion in concrete

Anodic and cathodic reactions are broadly referred to as “Half- Cell reactions”. The anodic reaction is the oxidation process, which results in the loss of metal, while the „catholic reaction" is the reduction process which results in reduction of dissolved oxygen forming Hydroxyl Ions . De- passivation around rebar would bring down the pH value and would result to corrosion in rebar. Corrosion rate is affected by the following factors (i) The pH of the electrolyte in concrete which is affected mainly by the carbonation (ii) The availability of oxygen and capillary water (iii) The concentration of Fe2+ in concrete near the reinforcement .

CHLORIDE-INDUCED CORROSION

Chloride induced corrosion in reinforcement bars is important cause of deterioration in offshore and onshore marine environment. In saturated state chloride ions enter into concrete by ionic diffusion due to concentration gradient between the exposed surface and pore solution inside the concrete. The diffused chloride ions either can be dissolved in pore solution or bound to the cement hydrates chemically or physically along the diffusion path. The total chloride ions can be divided into two part one is bound and another one is free ions. The free ions diffuse the reinforcement and break the passive layer of reinforcement, these leads to reinforcement corrosion.

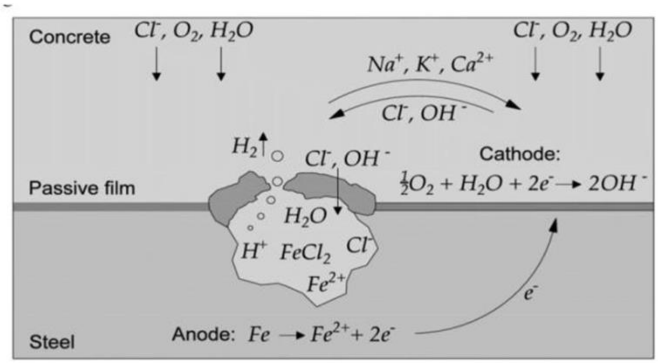

Fig 2 Chloride Induced Corrosion

CARBONATION INDUCED CORROSION

Carbonation is the one of the key factor which affect the durability of RC structures. Carbonation initiate the corrosion in RC structures, that leads to cracking and spalling of concrete in RC structures. Natural carbonation takes place at a relatively slow rate mainly due to the low concentration of CO2 in the atmosphere. But it can be faster in urban and industrial environments, Where the concentration of CO2 is relatively high and continues to rise. It leads to initiation of corrosion of the reinforcement, which can result in corrosion-induced damage. Carbonation affects both the concrete microstructure and the durability of steel in RC structures. Therefore it deserves much attention.

The chemical processes of carbonation in concrete involves reactions between dissolved carbon dioxide CO2 in the form of weak carbonic acid (H3CO3) and calcium hydroxide (Ca(OH)2) in the pore solution (or hydrated cement paste) resulting in the precipitation of calcium carbonate (CaCO3) in the concrete pores. Depletion of hydroxyl ions lowers the pore water pH from above 12.5 to below 9.0. Due to low pH the passive layer becomes unstable. This allowing general corrosion to occur if sufficient oxygen and water are present in the concrete.

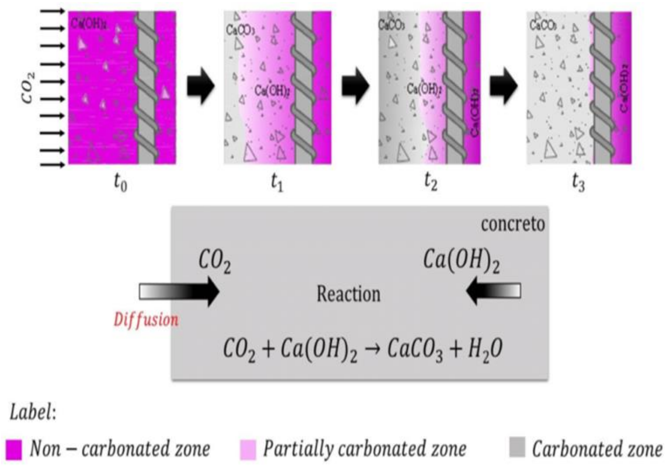

Fig 3. Carbonation induced corrosion

III. EXPERIMENTAL INVESTIGATION

Carbonation test was carried out in an existing building by the core cutting method. The testing of concrete cores is carried out according to the ASTM standard C42. The diameter of core specimens for the determination of concrete carbonation is should be at least three times the nominal size of aggregate used in the concrete. The length of the specimen should be twice its diameter. A core is cut by rotary cutting tool with diamond bits. The concrete core drilling machine is portable, but heavy and must be firmly supported against concrete to prevent movement. Water supply is needed to lubricate the cutter. The core shall be placed in water 24oC to 30oC for 48 hours. After that the core sample is open dried. The carbonation test is carried out by spraying the phenolphthalein indicator on the surface of the sample. The depth is measured using the vernier caliper.

The test model is located at anna nagar, Chennai, the area which has high traffic and higher emission of Co2 in Tamilnadu. The building is a 32 years old (G+4) residential building. The grade of concrete used for their construction is M30, the average humidity level is 70%, Co2 concentration in atmospheric is 416 ppm. Core cutting sample has 10cm diameter and 20cm height. The carbonation depth is 10mm.

Fig 4. Core cutting of samples

IV. MATHEMATICAL MODELLING

MATLAB is a programming and numeric computing platform used by millions of engineers and scientists to analyze data, develop algorithms, and create models.It combines a desktop environment tuned for iterative analysis and design processes with a programming language that expresses matrix and array mathematics directly.It includes the Live Editor for creating scripts that combine code, output, and formatted text in an executable notebook.

The Yoon et.al numerical model have been taken for the evaluation of concrete carbonation depth prediction in the MATLAB

$Xc = 2\times Dco2\times Cco2\times t$

a

Where,

$\times \; to$

t

nm

Dco2-co2diffusion coefficient (cm2/s), Cco2-atmoshperic co2 concentration(kg/m3), t-time period(year) to- reference period(a year), nm- age factor.

Cco2= [(12.61×log(t)) 95.172]

Dco2=1.64× × 2 2

a = 0.75×Ce×Ccao×ah×(Mco2/Mcao) ah= 1- ×

The reference period is taken as to=1989 t=varies from 1990 to2200

PREDICTION OF CARBONATION DEPTH WITH VARIOUS RELATIVE HUMIDITY LEVELS

RH=50,60,70,80,90,100

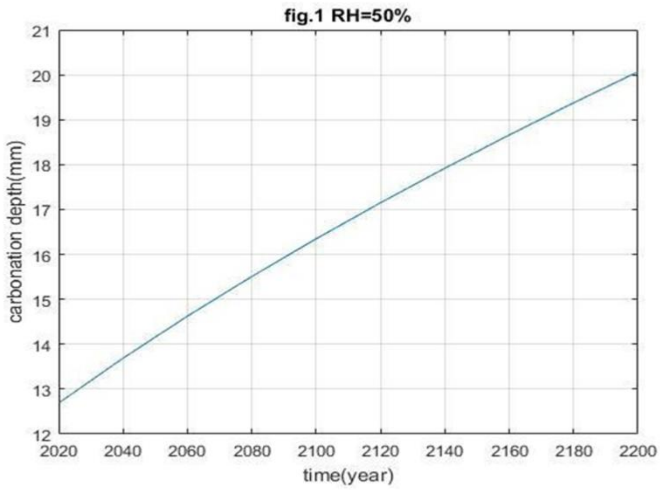

Fig 5. Carbonation depth at RH=50%

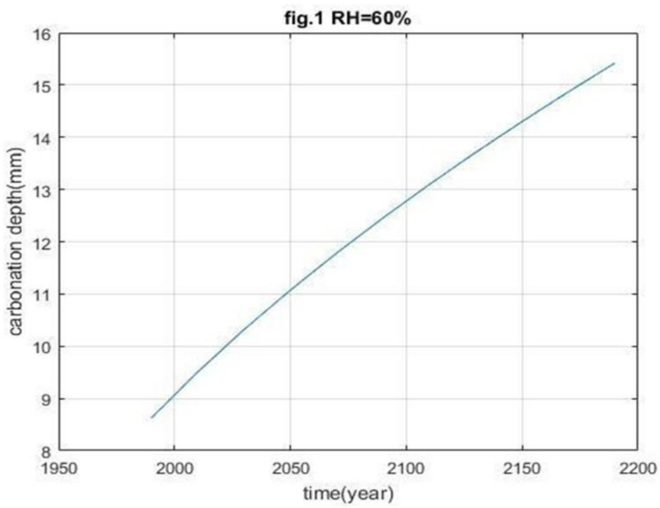

Fig 6. Carbonation depth at RH=60%

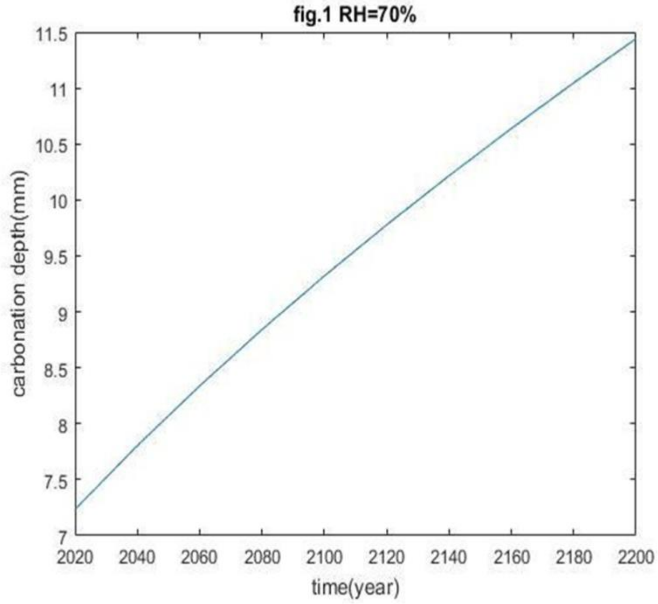

Fig 7. Carbonation depth at RH=70%

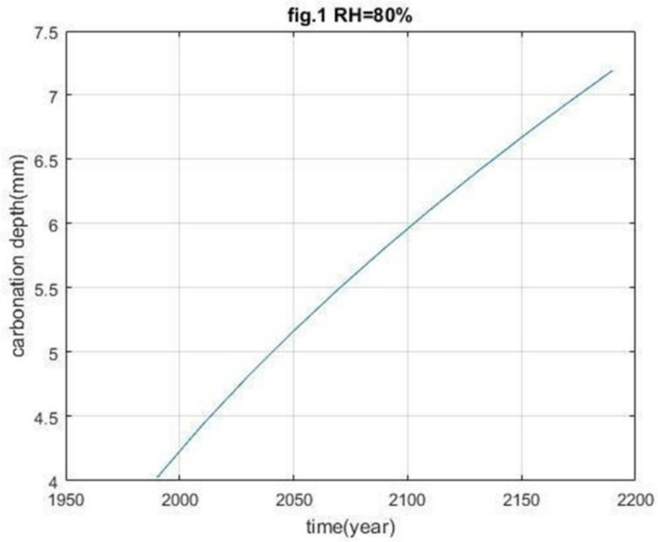

Fig 8. Carbonation depth at RH=80%

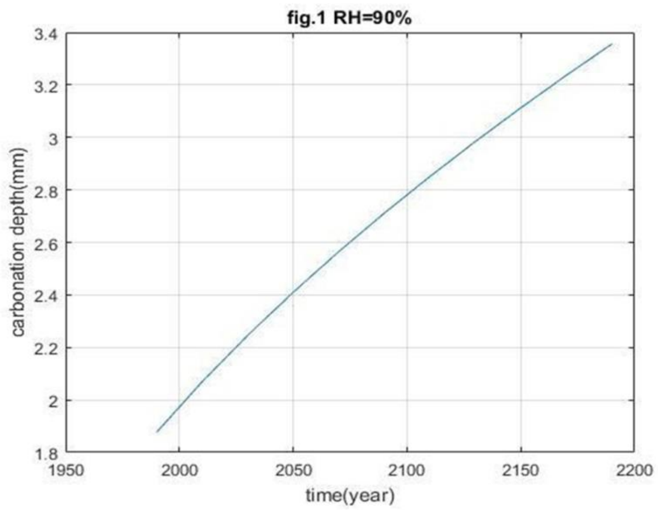

Fig 9. Carbonation depth at RH=90%

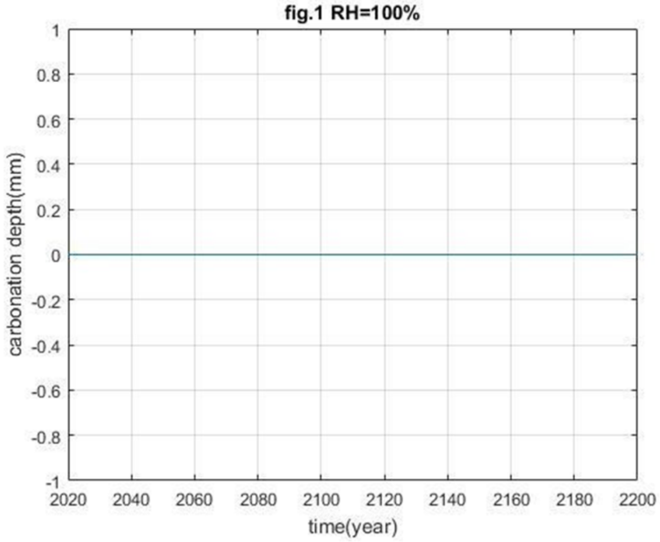

Fig 10. Carbonation depth at RH=100%

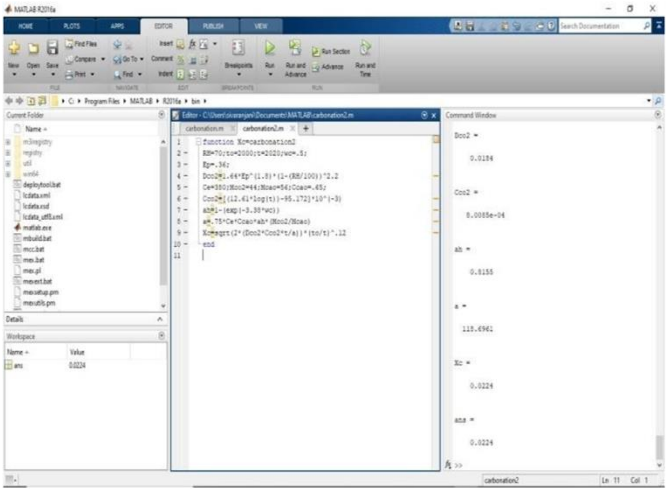

Fig 11. Modelling in MATLAB with different time period- algorithm.

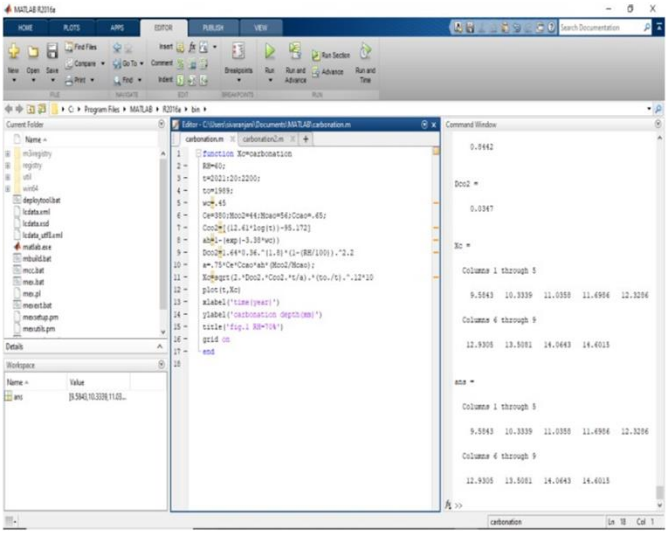

Fig 12. Modelling in MATLAB with an different humidity levels -algorithm.

PREDICTION OF CARBONATION DEPTH WITH VARIOUS W/C RATIO

The relative humidity is taken as constant 65%

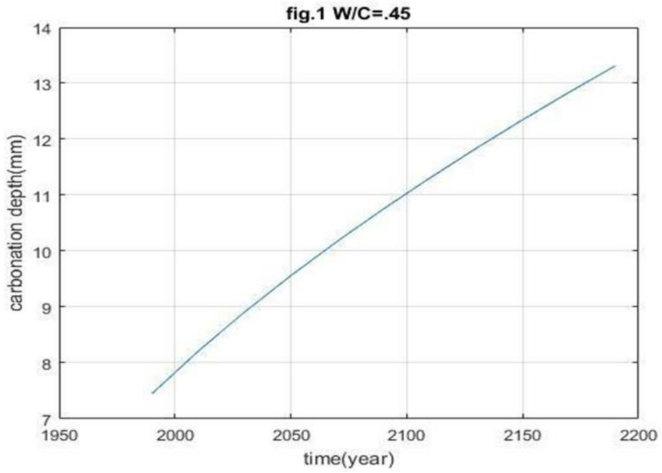

Fig 13. Carbonation depth at W/C=0.45

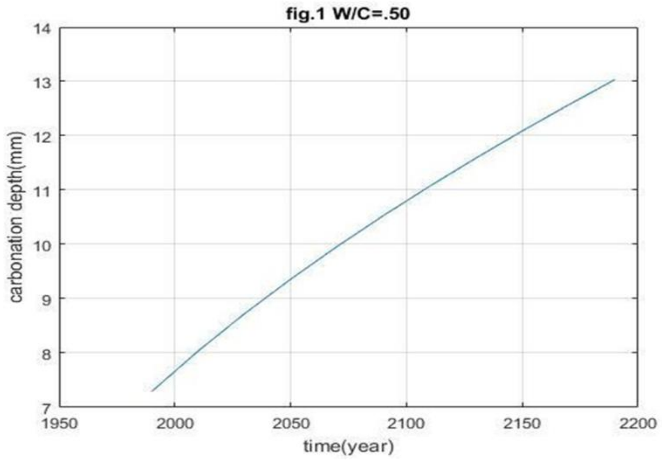

Fig 14. Carbonation depth at W/C=0.5

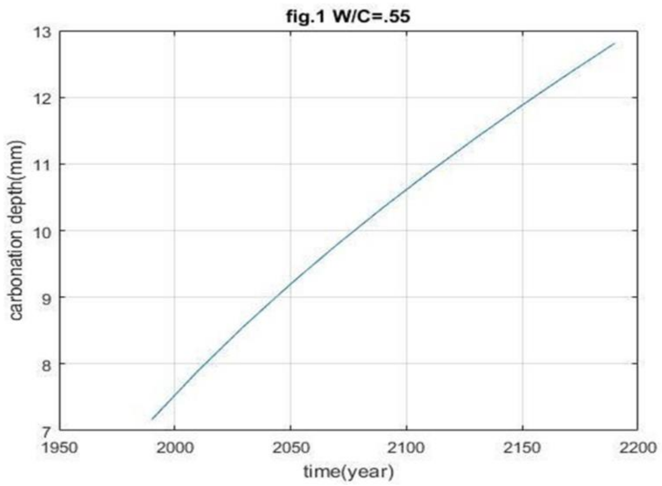

Fig 15. Carbonation depth at W/C=0.55

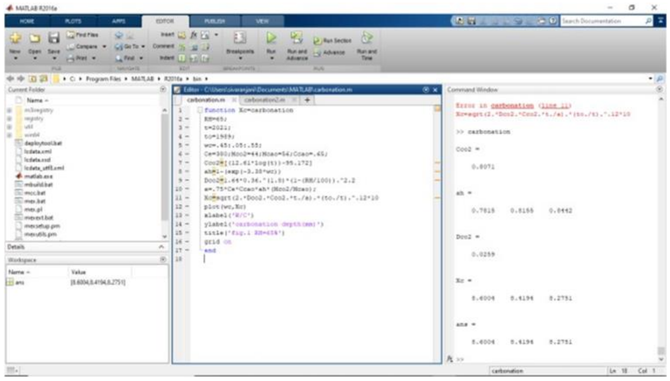

Fig 16. Modelling in MATLAB with different w/c ratio –algorithm

V. CONCLUSION

- From the numerical evaluation of the concrete carbonation, Relative humidity and Water cement ratio and Concentration of co2 has major role in concrete carbonation that increase the concrete carbonation process.
- Higher cement content in concrete increase the resistance of carbonation in concrete.
- From the results shows that the higher water cement ratio increase the carbonation depth.
- The age factor produce important role in evaluation it lies between 1.2 to 3.
- When the relative humidity value goes 100% the resistant against the carbonation in concrete is increases so there is no carbonation takes place.
- The concentration of Co2 in atmospheric air is 270 at1990 it will increase nearly two times 416 in 2021. The increasing Co2 concentration increase the carbonation process in concrete
- The numerical model depended more climatic factors, so we does not predict absolute values of carbonation depth but get the nearer values.
- The maximum values of concrete carbonation occurs at RH values 50%to 65% .
- The plotting of graphs in MATLAB is easy and the comparrision are get simultaneously
- The prediction of carbonation depth using the mathematical modelling software MATLAB is user friendly and it gives the optimum values .

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