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Tel No. (091)(033) 23671945-46 Fax No. 033 23671988
E-mail: kolkata-patent@nic.in
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G.A.R.6
[See Rule 22(1)]
RECEIPT

Docket No 25704

Date/Time 2022/08/28 20:15:41

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CBR Detail:

Sr. No	Ref No./Application No.	App. Number	Amount Paid	C.B.R. No	Form Name	Remarks
1	E-12/694/2022/KOL	202231049079	2500	10564	FORM 9	
2	202231049079	TEMP/E-1/56165/2022-KOL	1600	10564	FORM 1	EFFECTS OF WATER/CEMENT RATIO AND CURING TIME ON THE CARBONATION PROCESS OF REINFORCED CONCRETE STRU

TransactionID	Payment Mode	Challan Identification Number	Amount Paid	Head of A/C No
N-0001013602	Online Bank Transfer	2808220005299	4100.00	1475001020000001

Total Amount : ₹ 4100.00
Amount in Words: Rupees Four Thousand One Hundred Only
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Dr.D.SENTHIL KUMARAN, M.E., Ph.D., (NUS)
Principal
SSM Institute of Engineering and Technology
Kuttathupatti Village, Sindalagundu (Po),
Palani Road, Dindigul - 624 002.

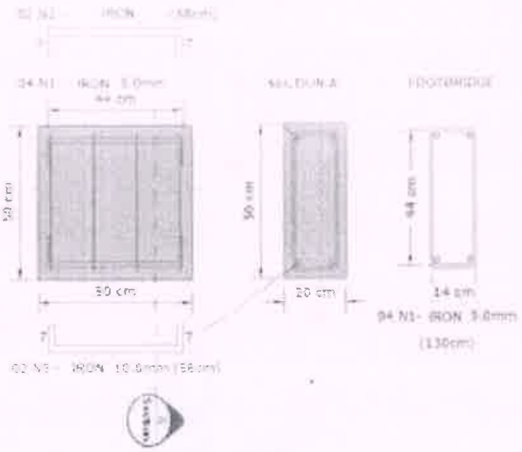

FIG 1 - Detailing of the beams

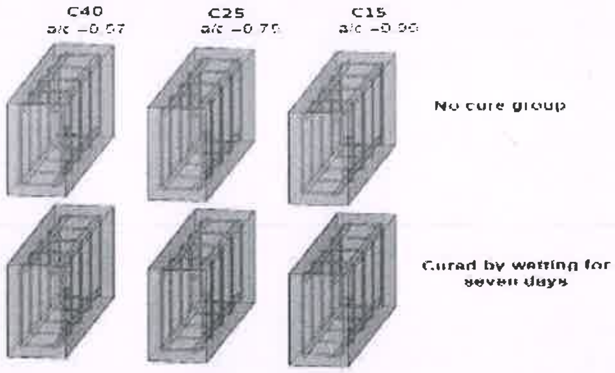

FIG 2 - Test groups

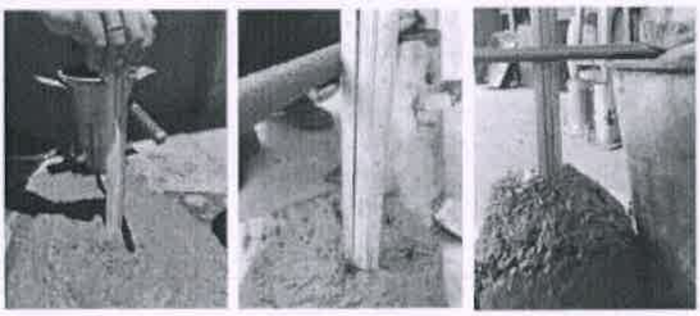

FIG 3 - Slump test

Dr.D.SENTHIL KUMARAN M.E., Ph.D., (IUS)
Principal
SSM Institute of Engineering and Technology
Kuttathupatti Village, Sindalagundu (Po),
Palani Road, Dindigul - 624 002.

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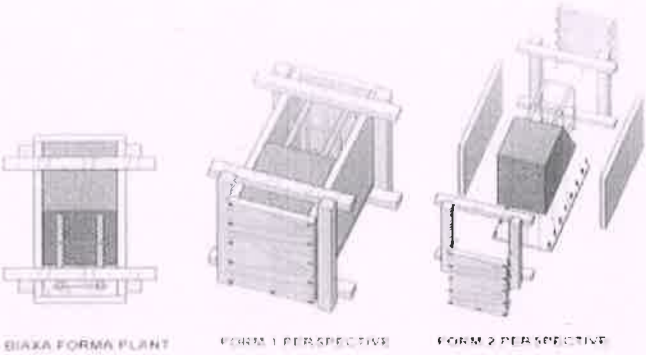

FIG 4 - Sketch of the formwork system

FIG 5 - Molding of the beams

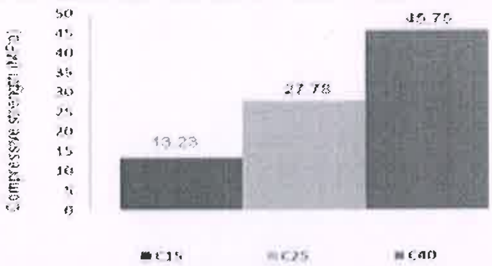

FIG 6 - Compressive strength

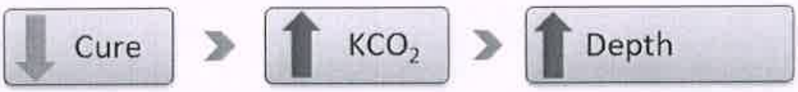

FIG 7 - Effects of curing time on concrete carbonation

FIG 8 - Effects of the w/c ratio on concrete carbonation

Dr.D.SENTHIL KUMARAN M.E., Ph.D., (NUS)
Principal
SSM Institute of Engineering and Technology
Kuttathupatti Village, Sindalagundu (Po),
Palani Road, Dindigul - 624 002.

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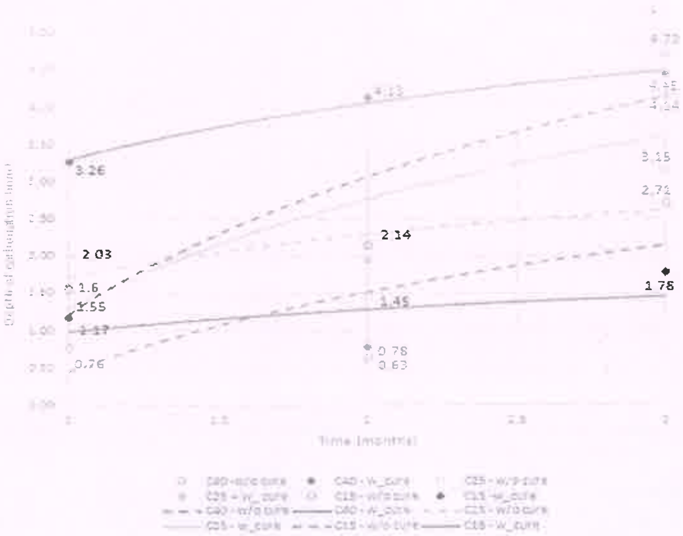

FIG 9 – Tuutti method carbonation fronts

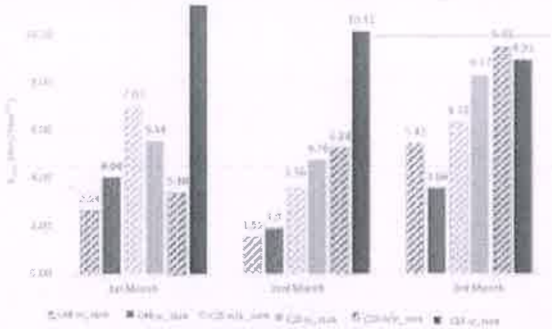

FIG 10 - Carbonation Speed

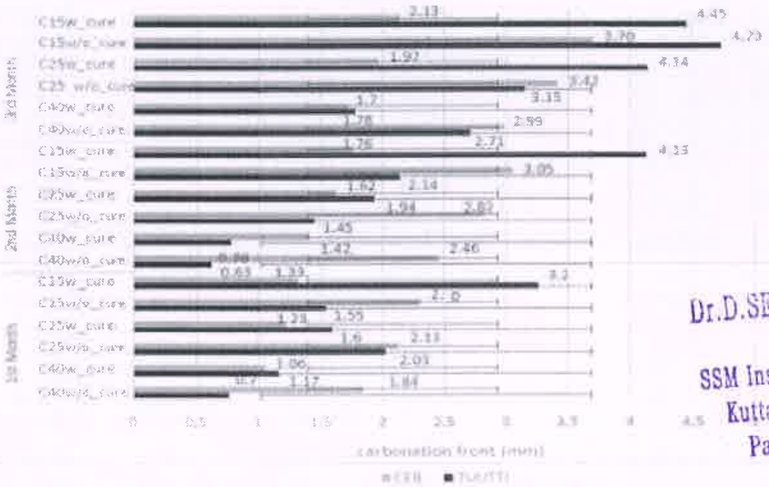

FIG 11 - Estimated and actual carbonation fronts

Dr.D.SENTHIL KUMARAN M.E.,Ph.D.,
Principal
SSM Institute of Engineering and Technology
Kuttathupatti Village, Sindalagundu (Po),
Palani Road, Dindigul - 624 002.

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Signature:
Applicant(s) Name: Dr. S. Sriram et. al.

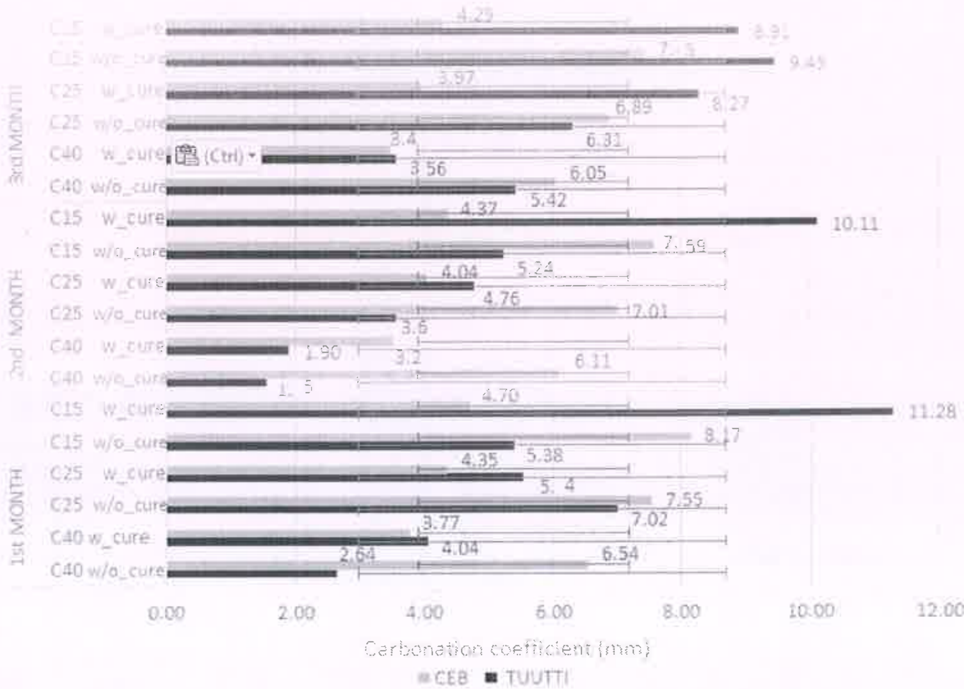

FIG 12 - Estimated and actual carbonation coefficients

FIG 13 - Effects of curing time on concrete carbonation

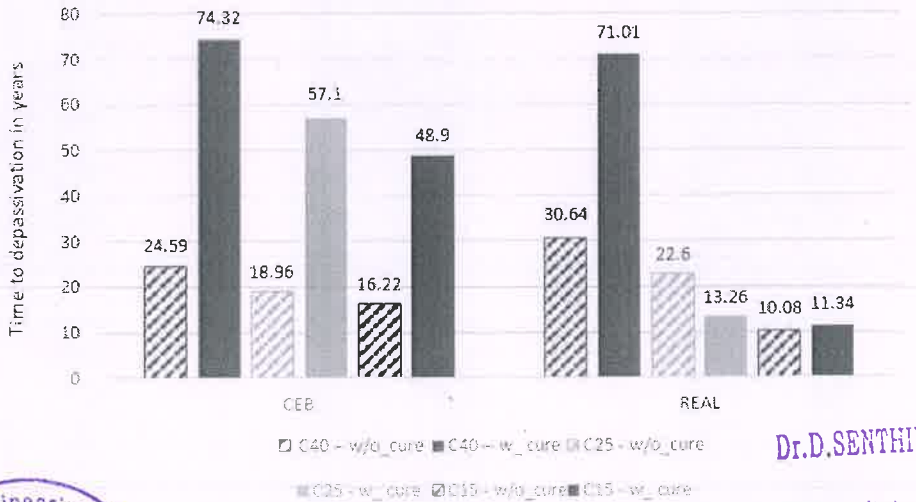

FIG 14 - Project lifetime prediction

Dr.D.SENTHIL KUMARAN, M.E., Ph.D., (NUS)
Principal
SSM Institute of Engineering and Technology
Kuttathupatti Village, Sindalagundu (Po),
Palani Road, Dindigul - 624 002.

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Signature:
Applicant(s) Name: Dr. S. Sriram et. al.

Applicant(s) Name: Dr. S. Sriram et. al.

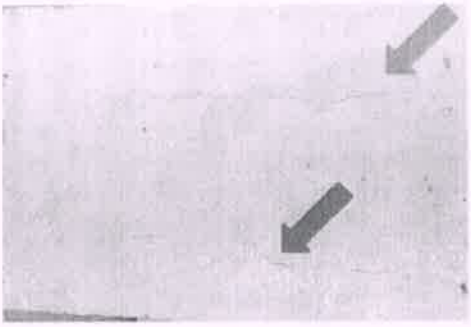

FIG 15 - Occurrence of cracks

Dated this 28th day of August, 2022

Dr.D.SENTHIL KUMARAN, M.E., Ph.D., (UG)
Principal
SSM Institute of Engineering and Technology
Kuttathupatti Village, Sindalagundu (Po),
Palani Road, Dindigul - 624 002.

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Signature:
Applicant(s) Name: Dr. S. Sriram et. al.

FORM 1 THE PATENTS ACT 1970 (39 of 1970) and THE PATENTS RULES, 2003 **APPLICATION FOR GRANT OF PATENT** (See section 7, 54 and 135 and sub-rule (1) of rule 20)	(FOR OFFICE USE ONLY)

	Application No.	
	Filing date:	
	Amount of Fee paid:	
	CBR No:	
	Signature:	
1. APPLICANT'S REFERENCE / IDENTIFICATION NO. (AS ALLOTTED BY OFFICE)		

2. TYPE OF APPLICATION [Please tick (✓) at the appropriate category]

Ordinary (✓)		Convention ( )		PCT-NP ( )	
Divisional ( )	Patent of Addition ( )	Divisional ( )	Patent of Addition ( )	Divisional ( )	Patent of Addition ( )

3A. APPLICANT(S)

Name in Full	Nationality	Country of Residence	Address of the Applicant
1. Dr. S. Sriram	INDIAN	India	Assistant Professor, Faculty of Engineering and Technology, Assam Down Town University, Sankar Madhab Path, Gandhi Nagar, Panikhaiti, Guwahati, Assam, India. Pincode - 781026
2. Dr. Rakesh Kumar Pandey	INDIAN	India	Associate Professor, Department of Civil Engineering, MATS University Raipur, India-493441
3. Dr. Shubhlakshmi Tiwari	INDIAN	India	Associate Professor and Head of Department, Department of Civil Engineering, Chouksey Engineering College, Bilaspur, NH49 Lalkhadan Bilaspur 495001
4. Mrs. Rolly vaishnav	INDIAN	India	Assistant professor, Department of Civil Engineering

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Dr.D.SENTHIL KUMARAN, M.E., Ph.D., (NUS)
Principal
SSM Institute of Engineering and Technology
Kuttathupatti Village, Sindalagundu (Po),
Palani Road, Dindigul - 624 002.

			Chouksey Engineering College, Bilaspur, NH49 Lalkhadan Bilaspur 495001
5. Mr. Himanshu Namdeo	INDIAN	India	Assistant professor, Department of Civil Engineering, Chouksey Engineering College, Bilaspur, NH49 Lalkhadan Bilaspur 495001
6. Mr. M. P. Karthik	INDIAN	India	Assistant Professor, Department of Civil Engineering, SSM Institute of Engineering and Technology, Palani Highway, Sindalagundu Post, Dindigul – 624002.
7. Dr. Sumit Gandhi	INDIAN	India	Associate Professor and Head of Department, Department of Civil Engineering, Jaypee University of Engineering and Technology, Guna.
8. Mr. Arvind Viswakarma	INDIAN	India	Assistant Professor, Department of Civil Engineering, Oriental University, Indore - 453555
9. Mr. Mohit Kumar Prajapati	INDIAN	India	Faculty, Department of Civil Engineering, School of Engineering and Technology, Vikram University, Ujjain, Madhya Pradesh, 456010
10. Dr. Ravindra D Nalawade	INDIAN	India	Faculty, Department of Civil Engineering, AISSMS College of Engineering Pune - 411001

Natural Person (✓)	Other than Natural Person		
	Small Entity ( )	Startup ()	Others ()

4. INVENTOR(S) [Please tick (✓) at the appropriate category]

Are all the inventor(s) same as the applicant(s) named above?	Yes (✓)	No ()

If "No", furnish the details of the inventor(s)

Name in Full	Nationality	Country of Residence	Address of the Inventor
Same as Applicant			

5. TITLE OF THE INVENTION

"Effects of Water/Cement Ratio and Curing Time on the Carbonation Process of

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Dr.D.SENTHIL KUMARAN, M.E., Ph.D., (NUS)
Principal
SSM Institute of Engineering and Technology
Kuttathupatti Village, Sindalagundu (Po),

Reinforced Concrete Structures”		
6. AUTHORISED REGISTERED PATENT AGENT(S)	IN/PA No.	
	Name	
	Mobile No.	
7. ADDRESS FOR SERVICE OF APPLICANT IN INDIA	Name	Dr. S. Sriram
	Postal Address	Assistant Professor, Faculty of Engineering and Technology, Assam Down Town University, Sankar Madhab Path, Gandhi Nagar, Panikhaiti, Guwahati, Assam, India. Pincode - 781026
	Telephone No.	
	Mobile No.	7010418249
	Fax No.	
	E-mail ID	esdiyeminfotech@gmail.com

~~8. IN CASE OF APPLICATION CLAIMING PRIORITY OF APPLICATION FILED IN CONVENTION COUNTRY, PARTICULARS OF CONVENTION APPLICATION~~

~~Country~~	~~Application Number~~	~~Filing date~~	~~Name of the applicant~~	~~Title of the invention~~	~~IPC (as classified in the convention country)~~

~~9. IN CASE OF PCT NATIONAL PHASE APPLICATION, PARTICULARS OF INTERNATIONAL APPLICATION FILED UNDER PATENT CO-OPERATION TREATY (PCT)~~

~~International application number~~	~~International filing date~~

~~10. IN CASE OF DIVISIONAL APPLICATION FILED UNDER SECTION 16, PARTICULARS OF ORIGINAL (FIRST) APPLICATION~~

~~Original (first) application No.~~	~~Date of filing of original (first) application~~

~~11. IN CASE OF PATENT OF ADDITION FILED UNDER SECTION 54, PARTICULARS OFMAIN APPLICATION OR PATENT~~

~~Main application/patent No.~~	~~Date of filing of main application~~

12. DECLARATIONS

(i) Declaration by theinventor(s)

(**In case the applicant is an assignee**: the inventor(s) may sign herein below or the

Dr.D.SENTHIL KUMARAN, M.E., Ph.D., (NUS)
Principal
SSM Institute of Engineering and Technology
Kuttathupatti Village, Sindalagundu (Po),
Palani Road, Dindigul - 624 002.

applicant may upload the assignment or enclose the assignment with this application for patent or send the assignment by post/electronic transmission duly authenticated within the prescribed period).

I/We, the above named inventor(s) is/are the true & first inventor(s) for this Invention and declare that the applicant(s) herein is/are my/our assignee or legal representative.

(a) Date 27/08/2022

(b) Name	(c) Signature
1. Dr. S. Sriram 2. Dr. Rakesh Kumar Pandey 3. Dr. Shubhlakshmi Tiwari 4. Mrs. Rolly vaishnav 5. Mr. Himanshu Namdeo 6. Mr. M. P. Karthik 7. Dr. Sumit Gandhi 8. Mr. Arvind Viswakarma 9. Mr. Mohit Kumar Prajapati 10. Dr. Ravindra D Nalawade	

~~**(ii) Declaration by the applicant(s) in the convention country**~~

~~**(In case the applicant in India is different than the applicant in the convention country:** the applicant in the convention country may sign herein below or applicant in India may upload the assignment from the applicant in the convention country or enclose the said assignment with this application for patent or send the assignment by post/electronic transmission duly authenticated within the prescribed period)~~

~~I/We, the applicant(s) in the convention country declare that the applicant(s) herein is/are my/our assignee or legal representative.~~

~~(a) Date~~

~~(b) Signature(s)~~

(c) ~~Name(s) of the signatory~~

(iii) Declaration by theapplicant(s)

I/We the applicant(s) hereby declare(s) that: -

- ☐ ~~I am~~/We are in possession of the above-mentioned invention.
- ☐ The ~~provisional~~/complete specification relating to the invention is filed with this application.
- ☐ ~~The invention as disclosed in the specification uses the biological material from India and the necessary permission from the competent authority shall be submitted by me/us before the grant of patent tome/us.~~
- ☐ There is no lawful ground of objection(s) to the grant of the Patent tome/us.
- ☐ ~~I am~~/we are the true &firstinventor(s).
- ☐ ~~I am/we are the assignee or legal representative of true & firstinventor(s).~~

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Dr.D.SENTHIL KUMARAN, M.E., Ph.D., (NUS)
Principal
SSM Institute of Engineering and Technology
Kuttathupatti Village, Sindalagundu (Po),
Palani Road, Dindigul - 624 002.

- ~~The application or each of the applications, particulars of which are given inParagraph-8, was the first application in convention country/countries in respect of my/our invention(s).~~
- ~~I/We claim the priority from the above mentioned application(s) filed in convention country/countries and state that no application for protection in respect of the invention had been made in a convention country before that date by me/us or by any person from which I/We derive thetitle.~~
- ~~My/our application in India is based on international application under PatentCooperation Treaty (PCT) as mentioned inParagraph-9.~~
- ~~The application is divided out of my /our application particulars of which is given inParagraph-10 and praythat this application may be treated as deemed to have been filed on DD/MM/YYYY under section 16 of theAct.~~
- ~~The said invention is an improvement in or modification of the invention particulars of which are given inParagraph-11.~~

13. FOLLOWING ARE THE ATTACHMENTS WITH THE APPLICATION

(a) Form 2

Item	Details	Fee	Remarks
Complete/ ~~Provisional~~ specification)#	No. of pages : 28		
No. of Claim(s)	No. of claims : 03 No. of pages: 01		
Abstract	No. of pages: 01		
No. of Drawing(s)	No. of drawings: 15 No. of pages: 05		

In case of a complete specification, if the applicant desires to adopt the drawings filed with his provisional specification as the drawings or part of the drawings for the complete specification under rule 13(4), the number of such pages filed with the provisional specification are required to be mentioned here.

(b) Complete specification (in conformation with the international application)/as amended before the International Preliminary Examination Authority (IPEA), as applicable (2copies).

(c) Sequence listing in electronic form

(d) Drawings (in conformation with the international application)/as amended before the International Preliminary Examination Authority (IPEA), as applicable (2copies).

(e) Priority document(s) or a request to retrieve the priority document(s) from DAS (Digital Access Service) if the applicant had already requested the office of first filing to make the priority document(s) available to DAS.

(f) Translation of priority document/Specification/International Search Report/International Preliminary Report on Patentability.

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Dr.D.SENTHIL KUMARAN, M.E., ~~Ph.D.~~, (NUS)
Principal
SSM Institute of Engineering and Technology
Kuttathupatti Village, Sindalagundu (Po),
Palani Road, Dindigul - 624 002.

(g) Statement and Undertaking on Form3
(h) Declaration of Inventorship on Form5
(i)Power of Authority
(j)**Total fee ₹..........in Cash/ Banker's Cheque /Bank Draft bearingNo......... Date on............. Bank.**

I/We hereby declare that to the best of my/our knowledge, information and belief the fact and matters slated herein are correct and I/We request that a patent may be granted to me/us for the said invention.

Dated this 27th day of August, 2022

Signature:
Name: Dr. S. Sriram et al.

To,
The Controller of Patents
The Patent Office, at Kolkata

Note: -
* Repeat boxes in case of more than one entry.
* To be signed by the applicant(s) or by authorized registered patent agent otherwise where mentioned.
* Tick ()/cross (x) whichever is applicable/not applicable in declaration inparagraph-12.
* Name of the inventor and applicant should be given in full, family name in thebeginning.
* Strike out the portion which is/are notapplicable.
* For fee: See FirstSchedule";

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Dr.D.SENTHIL KUMARAN, M.E., Ph.D., (NUS)
Principal
SSM Institute of Engineering and Technology
Kuttathupatti Village, Sindalagundu (Po),
Palani Road, Dindigul - 624 002.

FORM 2

THE PATENTS ACT, 1970(39 of 1970)

&

The Patent Rules, 2003

COMPLETE SPECIFICATION

(See section 10 and rule 13)

TITLE OF THE INVENTION

Effects of Water/Cement Ratio and Curing Time on the Carbonation Process of Reinforced Concrete Structures"

We, applicant(s)

NAME	NATIONALITY	ADDRESS
1. Dr. S. Sriram	INDIAN	Assistant Professor, Faculty of Engineering and Technology, Assam Down Town University, Sankar Madhab Path, Gandhi Nagar, Panikhaiti, Guwahati, Assam, India. Pincode - 781026
2. Dr. Rakesh Kumar Pandey	INDIAN	Associate Professor, Department of Civil Engineering, MATS University Raipur, India-493441
3. Dr. Shubhlakshmi Tiwari	INDIAN	Associate Professor and Head of Department, Department of Civil Engineering, Chouksey Engineering College, Bilaspur, NH49 Lalkhadan Bilaspur 495001
4. Mrs. Rolly vaishnav	INDIAN	Assistant professor, Department of Civil Engineering Chouksey Engineering College, Bilaspur, NH49 Lalkhadan Bilaspur 495001

Dr.D.SENTHIL KUMARAN, M.E., Ph.D., (NUS)
Principal
SSM Institute of Engineering and Technology
Kuttathupatti Village, Sindalagundu (Po),
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5. Mr. Himanshu Namdeo	INDIAN	Assistant professor, Department of Civil Engineering, Chouksey Engineering College, Bilaspur, NH49 Lalkhadan Bilaspur 495001
6. Mr. M. P. Karthik	INDIAN	Assistant Professor, Department of Civil Engineering, SSM Institute of Engineering and Technology, Palani Highway, Sindalagundu Post, Dindigul – 624002.
7. Dr. Sumit Gandhi	INDIAN	Associate Professor and Head of Department, Department of Civil Engineering, Jaypee University of Engineering and Technology, Guna.
8. Mr. Arvind Viswakarma	INDIAN	Assistant Professor, Department of Civil Engineering, Oriental University, Indore - 453555
9. Mr. Mohit Kumar Prajapati	INDIAN	Faculty, Department of Civil Engineering, School of Engineering and Technology, Vikram University, Ujjain, Madhya Pradesh, 456010
10. Dr. Ravindra D Nalawade	INDIAN	Faculty, Department of Civil Engineering, AISSMS College of Engineering Pune - 411001

The following specification particularly describes the nature of the invention and the mannerin which it is performed:

SSM Institute of Engineering and Technology DINDIGUL

Dr.D.SENTHIL KUMARAN, M.E., Ph.D., (NUS)
Principal
SSM Institute of Engineering and Technology
Kuttathupatti Village, Sindalagundu (Po),
Palani Road, Dindigul - 624 002.

[01] FIELD OF THE INVENTION

The present invention relates to study the applicability of polypropylene coated bamboo fibers in structural concrete.

[02] BACKGROUND OF THE INVENTION

One of the main causes of deterioration of reinforced concrete structures is carbonation, which triggers reinforcement corrosion. Carbonation comes from the surface, generating a front that creates two distinct pH zones, one with a pH around 9, carbonated area, and another with pH greater than 12, non-carbonated area. The front gradually advances into the concrete and when it reaches the reinforcement, it destabilizes the passivating oxide film, thus causing depassivation, making the reinforcement corrosion possible.

CO_2 penetrates the pores of the concrete with a certain ease, liquefies in the moisture existing in the structure and gives rise to carbonic acid (H_2CO_3), according to Equation 1, which despite being a weak acid, reacts with some constituents of the hydrated cement paste resulting in in water and calcium carbonate ($CaCO_3$). The compound that reacts with carbonic acid is calcium hydroxide ($Ca(OH)_2$). When calcium carbonate is formed, there is a consumption of the paste's alkalis and the consequent reduction of the pH of the solution existing in its pores, and when they reach the depth of the reinforcement, they leave it in a position to develop a corrosive process, however, calcium carbonate alone does not deteriorate concrete. The permeability of concrete to gases basically depends on the permeability of the cement paste, which in turn depends on the water/cement ratio (w/c) and the degree of hydration of the cement.

$$CO_2 + H_2O \rightarrow H_2CO_3 \quad (1)$$

This occurrence between the components of hydrated cement and CO_2, in a neutralization process, which transforms cementitious compounds into carbonates is called carbonation, as described in Equation 2.

Dr.D.SENTHIL KUMARAN, M.E., Ph.D., (NUS)
Principal
SSM Institute of Engineering and Technology
Kuttathupatti Village, Sindalagundu (Po),
Palani Road, Dindigul - 624 002.

$$H_2CO_3 + Ca(OH)_2 \rightarrow CaCO_3 + 2H_2O \quad (2)$$

In a structure, there are many agents that influence the carbonation coefficient, namely: the relative humidity (RH) of the environment, the moisture content, the CO_2 content and the permeability of the concrete. Curing effectiveness and the w/c ratio considerably interfere with permeability.

Precipitation above 2.5 mm ends up generating a very high relative humidity (above 80%), which significantly reduces the rate of carbonation. It is known that the carbonation rate is higher when the air humidity is between 40% and 80%, with enough water to cause CO_2 to dissolve, so that the pores are not fully saturated. The hypothesis that there is some relationship between carbonation and dew point should not be discarded, after all, if the humidity is at a certain percentage and the dew point is high, it means that CO_2 will be difficult to access.

The decrease in the diffusion coefficient is notorious when the relative humidity of the pores exceeds 60%. Carbonation is facilitated when the quality of the concrete is not adequate. High w/c ratio, small coating thicknesses, reduced amounts of cement and wetting and drying cycles are constraints to the speed of carbonation. Opposite to that, satisfactory curing methodology, large amounts of calcium hydroxide, addition of pozzolanic fly ash, good compaction, in addition to other factors that slow down the process.

The increasing hydration of cement justifies the tendency towards stabilization. Gradually the compactness of the concrete is increased as long as there is enough water. Added to this is the action of the transformation products, which also clog the surface pores, making it difficult for CO_2 to access, in addition to the material coming from the external environment, which enters the interior of the concrete. Calcium carbonate precipitates inside the pores, due to its very low solubility, it reduces the porosity of the concrete and, consequently, causes difficulty in advancing the carbonation front.

The permeability to gases is reduced in environments where humidity is imminent and that together with water, when in the pores, they inhibit the flow of gases, in addition to the eventual appearance of shrinkage microcracks on the exterior face of the concrete. This justifies the famous fact that greater carbonation depths are observed in places with drier climates (R.U. < 80%), or subject to cycles of wetting and drying.

[03] SUMMARY OF THE PRESENT INVENTION

After the practical application of the research, in addition to the field studies, it was possible to conclude that the model is indeed applicable at the national level and can be used as a model to predict the useful life of structures.

It was also observed that the curing time significantly influences the deterioration of the structure, not only in the first months of age but also for the entire shelf life, because the longer the curing time, the lower the carbonation front, in function of the lower degree of hydration. The higher the w/c ratio, the greater the carbonation front observed, which was expected, in the first month the velocity is high, because it has high porosity and permeability due to the non-complete hydration of the cement grains. From the second month, it is normal for this speed to drop, because the grains are already hydrated, the porosity is lower, the air permeability is also lower. It was noted that the consumption of cement significantly interferes in the carbonation front, being it a predominant factor. The beams will be evaluated over the years to see at what age the model does not apply with the same precision described.

[04] BRIEF DESCRIPTION OF THE DRAWINGS

The invention will be better understood and objects other than those set forth above will become apparent when consideration is given to the following detailed description thereof. Such description makes reference to the annexed drawings wherein:

FIG 1 - Detailing of the beams

FIG 2 - Test groups

FIG 3 - Slump test

FIG 4 - Sketch of the formwork system

FIG 5 - Molding of the beams

FIG 6 - Compressive strength

FIG 7 - Effects of curing time on concrete carbonation

FIG 8 - Effects of the w/c ratio on concrete carbonation

FIG 9 – Tuutti method carbonation fronts

FIG 10 - Carbonation Speed

FIG 11 - Estimated and actual carbonation fronts

FIG 12 - Estimated and actual carbonation coefficients

FIG 13 - Effects of curing time on concrete carbonation

FIG 14 - Project lifetime prediction

FIG 15 - Occurrence of cracks

DETAILED DESCRIPTION OF THE INVENTION

[05] Materials and methods

After defining the theme, a bibliographic study was carried out on published articles, books and standards, so that it was possible to understand the carbonation process.

Characterization of Materials

Composite Portland cement with filler was used, with a strength class of 40.0 MPa with the specifications regulated in IS 16415: 2015, as shown in Table 1.

The coarse and fine aggregates used were properly characterized with their definitions evaluated according to the requirements of the standard. The additive Mira Set 38 of the Grace brand was used with dispersant and set-retarding function, whose appearance is dark brown liquid, pH of 6.31 and specific mass of 1.141 g/cm^3, being free of chlorides and meeting specifications

Definition of Trace

The traces provided by a concreting plant differ in terms of mechanical strength, the w/c ratio and the consumption of materials. The mixture with the highest w/c ratio (0.96) has lower mechanical strength, reaching 15.0 MPa; the 0.75 w/c ratio trace was dosed to reach 25.0 MPa; and, finally, the trace of w/c ratio 0.57 was dosed to reach 40.0 MPa. The concrete received the names C15, C25 and C40 respectively, as shown in Table 1.

Table 1 - Consumption of mixtures in kg/m³

MIXTURE	C 15	C 25	C 40
CEMENT	193.0	236.0	314.0
NATURAL SAND	653.0	628.0	555.0
ARTIFICIAL SAND	400.0	380.0	340.0
BRAVE 9.5 MM	420.0	435.0	445.0
BRIDGE 19.0 MM	585.0	600.0	630.0
ADDITIVE	1.25	1.53	2.04
WATER	185.0	177.0	179.0

Beam characteristics

To evaluate the impact of the w/c ratio and the curing time on the carbonation front of the concrete, six reinforced concrete beams were molded in the dimensions 0.20 x 0.50 x 0.50 m with the respective w/c ratios 0, 57, 0.75 and 0.96, with two beams for each trace. For the beam reinforcements, stirrups with a diameter of 5.0 mm were adopted, with a spacing of 14.0 cm in 14.0 cm between them, and this spacing was adopted according to the standard, taking into account both the aspect of useful height and in terms of shear force. For the negative reinforcement, the diameter used was 8.0 mm and two rebars were placed at the top of the beam. The positive reinforcement with a diameter of 10.0 mm with two rebars at the bottom of the beam. All bars meet the requirements. FIG 1 shows the detail of the executed beams.

Determination of test groups

As shown in FIG 2, the six beams were divided into two test groups, the first one not receiving any type of curing and the second one being cured by wetting for seven days. The beams of the second group were cured with water three times a day. Each group has beams with different w/c ratios, being 0.57, 0.75 and 0.96.

molding process.

Cure and deform

The curing process was carried out by humidifying the surfaces of the beams, ensuring that they were saturated most of the time. The adopted curing times were zero and seven days. The stripping was carried out with appropriate equipment, avoiding excessive shocks or vibrations that could jeopardize the integrity of the concrete, preventing the appearance of cracks or impairing the adhesion of the concrete with the reinforcement. The curing and deforming processes were performed according to the recommendations.

Monitoring of environmental factors

The environmental conditions began to be monitored at the time of concrete execution, and after the de-moulding, they were measured again to evaluate the advance front of the deterioration of the concrete of the beams. This monitoring took place through Criffer's CO-6plus carbon dioxide meter.

[06] Carbonation tests

The on-site tests were carried out according to the step by step below:

I. Scarification was carried out on the surface of the concrete with a pickle with a depth equal to or less than the nominal cover of 30 mm;

II. A 1.0% phenolphthalein solution was sprayed on the scarified region;

III. After the application of the solution, the measurement of the depth of the carbonation front was carried out with the aid of a universal caliper. The measurement was performed at three different points, and the average of the three points was adopted as a result.

To determine the carbonation rate, the methodology described below was used. With the carbonation depth measured in loco using the previously mentioned method and considering the exposure time of the beams, the carbonation coefficient was calculated using the Tuutti (1982) model, according to Equation 3.

$$x_c = k_{CO2} * \sqrt{t} \quad (3)$$

Where: x_c = carbonation depth [mm];

k_{CO2} = carbonation coefficient [mm/year0.5];

t = exposure time [year].

These coefficients, as well as the actual carbonation depths, were later used for comparison with estimated values through Equation 4, provided in CEB Bulletin 34 (2006) and CEB Bulletin 55 (2010) regulations.

$$x_c = \sqrt{2 * k_e * k_c * R_c * C_{CO2}} * \sqrt{t} * w \quad (4)$$

Where: X_c = depth of carbonation [mm];

k_e = environmental coefficient [dimensionless];

k_c = cure coefficient [dimensionless];

R_c = effective resistance to carbonation [(mm2/year)/(kg/m3)];

C_{CO2} = CO_2 concentration [%];

t = exposure time [s];

w = climate coefficient [dimensionless].

The calculation of the environmental coefficient (k_e) was performed according to Equation 5. The values of the real relative humidity of the air were taken, while for the relative humidity values of reference, 65% was adopted according to the accelerated method of assessment of carbonation (ACC), from CEB Bulletin 34 (2006). The values of the exponents ge = 2.5 and fe = 5.0 were also taken from the ACC method.

$$k_e = \left[\frac{1-\left(\frac{RHreal}{100}\right)^{fe}}{1-\left(\frac{RHref}{100}\right)^{fe}}\right]^{ge} \quad (5)$$

Where: RHreal = relative humidity of the carbonated layer [%];

RHref = reference relative humidity [%];

Concrete production

The concrete mixtures were carried out in a concrete mixer with a nominal capacity of 370 liters, respecting the sequence of launching the materials in the concrete mixer and the concrete kneading time. After finishing the concreting and respecting the rest period, the concrete was thrown in wheelbarrows and transported to the place of concreting.

Technological control of concrete

For each concrete, three specimens were removed to rupture at 28 days, which were molded and ruptured, and the compressive strength of each trace was then verified. For the technological control of the concrete in the fresh state, the slump test was carried out, which is the slump of the cone trunk to measure consistency and fluidity (FIG 3). Table 2 shows the results obtained.

Table 2 - Reduction of the concrete cone trunk

Feature	*Slump test* (mm)	fck (MPa)
C15	225	13.23
C25	155	27.78
C40	140	45.75

Beam molding

The C15 and C25 concrete beams were molded on February 22, 2022 and the C40 beams on February 23, 2022. The forms used were produced in wood with plywood boards to maintain the geometry of the six structural parts, ensuring water tightness of the concrete in the fresh state so that cream does not leak, until the concrete becomes self-supporting. The formwork project was not carried out, but care was taken to check the alignment of the side panels of the beams, ensuring that they were locked with ties so that any type of mobility of the set would not occur. All molds were properly moistened before applying the release agent. The beam was concreted in layers; the concrete was densified by hitting the formwork with a rubber mallet. FIG 4 presents an outline of the formwork system used and FIG 5 records the

Exponents f (5.0) and g (2.5) [dimensionless].

The curing condition coefficient was determined according to Equation 6. The curing times were entered according to FIG 2. An average value was set for the regression exponent, in addition to a tolerable standard deviation.

$$k_c = \left(\frac{tc}{7}\right)^{bc} \qquad (6)$$

Where: bc = regression exponent [dimensionless];

tc = curing period [days];

bc = -0.567;

Sd = standard deviation = 0.024 [dimensionless].

The CO_2 concentration is obtained through Equation 7. The values of CO_2 concentration in the atmosphere and additional were obtained by means of the CO-6 Plus device of the Criffer brand, obtaining an average of 0.039%.

$$Cs = Cs{,}atm + Cs{,}emi \qquad (7)$$

Where: C_S = CO_2 concentration [kg/m³];

$C_{S,atm}$ = atmospheric CO_2 concentration [kg/m³];

$C_{S,emi}$ = additional concentration of CO_2 [kg/m³].

The resistance to carbonation of concrete is defined by Equation 8. Obtained through the relationship between the diffusivity of CO_2 and the content of calcium oxide (CaO) present in each cubic meter of concrete

$$R_c = \frac{Dco2}{a} \qquad (8)$$

Where: R_c = resistance to natural carbonation of concrete;

Dco2 = CO_2 diffusion coefficient in carbonated concrete [m²/s];

a = calcium oxide (CaO) content in 1.0m³ of concrete [kg/m³];

Dr.D.SENTHIL KUMARAN, M.E., Ph.D., (NUS)
Principal
SSM Institute of Engineering and Technology
Kuttathupatti Village, Sindalagundu (Po),
Palani Road, Dindigul - 624 002

In turn, the CO_2 diffusivity depends on the characteristic strength of the concrete, according to Equation 9.

The characteristic strengths of concrete were obtained through compression tests. The value of cement consumption is required, and this value is used corresponding to that of each mix. The CaO content present in $1m^3$ of cement was provided by the manufacturer, which is 60%. An interpolation was performed to find the value of the degree of hydration according to Table 2. Molar mass values are fixed for each molecule.

$$a = 0.75 \times C \times CaO \times \alpha h \times \left(\frac{MCO2}{MCaO}\right) \qquad (10)$$

Where: a = calcium oxide (CaO) content in $1.0m^3$ of concrete [kg/m^3];

C = cement consumption [kg/m^3];

CaO = clinker composition of Portland cements that varies from 59% to 67%;

αh = degree of hydration of the cement which is equivalent to 1.0 [dimensionless]; MCaO = molar mass of 56.0774 [g/mol];

MCO_2 = molar mass of 44.01 [g/mol].

Table 2 - Degree of hydration as a function of the w/c ratio

a/c	αh (%)
0.4	60
0.6	70
0.8	80

To obtain the climatic coefficient, Equation 11 is used. It is necessary to calculate the average of days with precipitation equal to or greater than 2.5 mm/year for the ToW factor. In the first month, the beams were exposed for eleven days with rain, until the second month it was sixteen days and finally, seventeen days until the third month.

The adopted regression exponent was recommended by CEB Bulletin 34 (2006), respecting the standard deviation.

Dr.D.SENTHIL KUMARAN, M.E., Ph.D., (NUS)
Principal
SSM Institute of Engineering and Technology
Kuttathupatti Village, Sindalagundu (Po),
Palani Road, Dindigul - 624 002.

$$W = \left(\frac{t_0}{t}\right)^{\frac{(p_{SR} \cdot ToW)^{b_w}}{2}} \quad (11)$$

Where: t0 = reference time [years]; t = beam lifetime [years];

ToW = days with precipitation hNd ≥ 2.5 mm per year/365; pSR = probability of exposure to rain [dimensionless];

bw = regression exponent [dimensionless]. m (average value) = 0.446

s (standard deviation) = 0.163

[07] Results and discussions

Compressive strength

Three traces were produced (C15, C25 and C40) whose nomenclature derives from the expected compressive strengths. During the production of the mixtures, technological control was carried out and the results of the characteristic compressive strengths of concrete are shown in FIG 6.

C25 and C40 concretes reached values higher than expected, reaching 27.78 MPa and 45.75 MPa, respectively. Only C15 did not reach the expected value, however this is not a structural concrete and the objective of this research is based on the analysis of the durability of the mixture.

Analysis of data obtained by the estimation model

It was observed that the curing time, the w/c ratio and the cement consumption influence the carbonation depth (**FIG 7**).

In the first month, the uncured beams presented carbonation depth with higher values in relation to the cured beams, this pattern also extended to the second and third months.

Based on the values obtained, it was observed that the curing time has a considerable influence on the carbonation depth. When observed from the first to the third month, the carbonation front increases for all concretes, so that the shorter the curing time, the greater the depth. Comparing the results between beams with and without curing, it is possible to notice that with the passage of time the percentage of increase in deterioration is greater in concrete without curing, presenting values greater than 70%, therefore, the curing in fact influences the whole the useful life of the structure.

The w/c ratio is another important parameter, which acts on the strength of the concrete. Thus, it is understood that the higher the w/c ratio, the lower the strength of the concrete, consequently also influencing the rate of deterioration and the depth of carbonation (FIG 8). At three months, the C15 beams expressed for carbonation depth, higher values in relation to C25, which in turn were higher than in the C40 beams.

Regarding the analysis of the w/c ratio, it was not possible to measure the percentages of variation between the concretes, since the concretes not only vary in water content, but also in cement consumption and hydration degrees.

To verify which of the factors most influences the carbonation front in the model, the values of cement consumption, curing time and fck were doubled and halved. It was noted that by reducing the cement consumption by half the carbonation front would increase approximately 40%, and by doubling the consumption the front would reduce around 30%. Regarding the curing time, when reducing it to three days, the deterioration can be up to 30% greater, and when increasing it to fourteen days, it can increase by up to 20%. As for the fck, by increasing it it is possible to reduce the deterioration by approximately 10%. The other factors were also analyzed, however they presented impact percentages to those mentioned above.

Analysis of data obtained by the Tuutti model

The graph presented in FIG 9 explains the data found in the field. The carbonation depths in the curing beams showed higher values than the uncured beams, distorting the theory that the longer the curing time, the lower the carbonation front. One-month-old concrete is not fully hydrated, that is, it still has a significant amount of pores, so it is natural that deterioration occurs at an accelerated rate at early ages. As it is not a homogeneous material, it is expected that the difference in carbonation depth of the beams with and without curing will occur. Therefore, it is possible that the internal networks of capillary pores in the tested sites are extensive, either due to the presence of water in the curing process or as a result of the hydration process, however, more research would be necessary to evaluate this hypothesis.

Based on literature studies, the expectation was that the higher the characteristic strength of concrete (fck), the lower the rate of deterioration, which was confirmed during field tests (FIG 10). The values obtained followed the same parameter as estimated, the beams with the highest w/c ratio had greater carbonated depth, because the lower the strength of the concrete, the more porous the microstructure of the mixture, increasing the CO_2 diffusivity, accelerating carbonation.

It is possible to observe a difference in results (KCO_2) from the first to the third month, where the beams without cure C40 and C15 have an increase rate of 105.30% and 179.59% respectively, whereas the C25 beam has a decrease of 10.11%. The beams with cure C40 and C15 fell by 11.88% and 21.01% in that order, however C25 rose by 49.28%. With the exception of C25, the cured beams showed a drop rate while the uncured beams rose significantly. This result is expected because the concrete gradually hydrates, with this the pores are clogged, making it more and more difficult for the penetration of CO_2, because the greater the degree of hydration, the lower the porosity.

Comparison of actual results with estimated ones

After the comparative analysis between the two methods (FIG 11), in order to assess whether the estimated model is close to the real value, it was concluded that the carbonation fronts measured in the field were close to the values estimated by the standard.

Table 3 presents the front data and carbonation coefficient of the concretes in the first three months. It was possible to identify a variation between the CEB Bulletin 55 model (2010) and the on-site measurement. The first month showed a pattern in carbonation depth: where the value measured in capo is higher than CEB in cured beams, but lower in uncured beams. In the second month, this pattern was maintained, with the exception of the C40 with cure, where the measured carbonation depth was lower than that estimated by the CEB.

Analyzing the measured results of the first month, the cured C40 and C15 beams had a greater depth of carbonation unlike the C25, in the second month all the cured beams had a greater carbonation depth in relation to the beams without cure, which contradicts with the CEB. The difference in result between the estimated and the real one is due to the climatic difference and also to the quality of the concrete in terms of dosage, production and application of the mixture.

Table 3 - Estimated and actual carbonation depths and coefficients

1st month	Age (years) = 0.083333333											
	C15 w/o_cure		C15 w_ cure		C25 w/o_cure		C25 w_ cure		C40 w/o_cure		C40 w_ cure	
	CEB	Real	CEB	Real	CEB	Real	CEB	Real	CEB	Real	CEB	Real
X_c (t) (mm)	2.30	1.55	1.33	3.26	2.13	2.03	1.23	1.60	1.84	0.76	1.06	1.17
K_{CO2} (mm/Year$^{0.5}$)	8.17	5.38	4.71	11.28	7.55	7.02	4.35	5.54	6.54	2.64	3.77	4.04

2nd month	Age (years) = 0,16666667											
	C15 w/o_cure		C15 w_ cure		C25 w/o_cure		C25 w_ cure		C40 w/o_cure		C40 w_ cure	
	CEB	Real	CEB	Real	CEB	Real	CEB	Real	CEB	Real	CEB	Real
X_c (t) (mm)	3.05	2.14	17.6	4.13	2.82	1.45	1.62	1.94	2.46	0.63	1.42	0.78
K_{CO2} (mm/Year$^{0.5}$)	7.59	5.24	4.37	10.11	7.01	3.56	4.04	4.76	6.11	1.56	3.52	1.9

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Dr.D.SENTHIL KUMARAN, M.E., Ph.D., (NUS)
Principal
SSM Institute of Engineering and Technology
Kuttathupatti Village, Sindalagundu (Po),
Palani Road, Dindigul - 624 002.

3rd month	Age (years) = 0.25											
	C15 w/o_cure		C15 w_ cure		C25 w/o_cure		C25 w_ cure		C40 w/o_cure		C40 w_ cure	
	CEB	Real	CEB	Real	CEB	Real	CEB	Real	CEB	Real	CEB	Real
X_c (t) (mm)	3.70	4.73	2.13	4.45	3.42	3.15	1.97	4.14	2.99	2.71	1.72	1.78
K_{CO2} (mm/Year$^{0.5}$)	7.45	9.45	4.29	8.91	6.89	6.31	3.97	8.27	6.05	5.42	3.48	3.56

The deterioration of concrete takes place on a logarithmic scale, that is, at the beginning there is a considerable speed, due to the presence of $Ca(OH)_2$, and as the compound is consumed in the chemical reactions, this speed is reduced, resulting in an advance of the carbonation front. Carbonation does not actually stop, but it happens at a very low speed, making the effects of its occurrence over time imperceptible, and its effects are neglected.

The lower the amount of carbonatable products, the higher the carbonation rate. It can also be taken into account the fact that the model considers only the chemical reaction of $Ca(OH)_2$ with CO_2 – as it is the main one – however there are other acid gases, such as hydrogen sulfide (H2S) and carbon dioxide. sulfur (SO_2) that can also carbonate the concrete. In addition, concrete has other carbonatable alkaline components, such as potassium hydroxide (KOH), sodium hydroxide (NaOH) and alkali silicates.

It is concluded that, at least in the first months, the model is applicable, and the values obtained show small discrepancies in relation to those measured in loco. With the exception of the cured beams, the estimated values of the first month showed greater carbonation depth, in the second month only the cured C25 and C15 beams remained in the pattern of the first month. The differences arise from the non-homogeneity of the concrete, in addition to the deviations present in the equations. FIG 12 illustrates the comparison of KCO_2.

It is clear that the curing time in the first month is crucial, because it can significantly interfere with the depth of deterioration, and it helped to increase the degree of hydration of the concrete, reducing the diffusivity of CO_2 by reducing the diameters of the capillary pores. Note that the differences between the KCO_2 results are greater in the second month compared to the first. Inadequate compaction and curing produce an excessive amount of pores, mainly on the surface of the concrete, facilitating the diffusion of CO_2 to its interior, which are parameters that favor the carbonation rate (FIG 13).

According to the real and estimated values of the carbonation coefficients obtained in the third month and using the Tuutti (1982) model, the times until the depassivation of the beams reinforcement were calculated, whose nominal cover must be 30 mm according to the standard. The time values are shown in FIG 14.

It is observed that the lower the characteristic strength of the concrete, the shorter the period of time elapsed until the depassivation of the steel. This pattern was maintained regardless of curing the structural elements.

When evaluating the results estimated by the model, it is noted that the beams produced with C25 and C40, which underwent the seven-day curing process, would reach the minimum project life limit of 50 years. It is also noticeable the importance of the curing process in the durability of reinforced concrete structures, since none of the concretes, both in the results of the model and in the real results, reached the minimum limit of project life.

Based on the actual service life prediction results, it is possible to note that only cured beams produced with C40 concrete would reach the minimum project life time. However, it is likely that all concretes will reach the minimum project life, because as already explained, the carbonation rate decelerates as a function of time. To verify this hypothesis, the calculation of the time until depassivation must be performed with coefficient values obtained in beams with more advanced ages.

[08] Complementary analyzes

In addition to all the data already analyzed and mentioned above, cracks were observed soon after the beams were molded (FIG 15), resulting from the effect of plastic shrinkage, with greater incidence in the elements without curing. The cracks were concentrated in the positions of the reinforcements, which can be explained by two reasons: i) in the region of the reinforcements, the area is reduced, resulting in an increase in the concentration of water leaving voltage; ii) the adsorbed water film on the bars increases the amount of water, resulting in a higher outlet pressure.

Plastic shrinkage is the loss of water in its fresh state causing a reduction in the volume of the concrete, which does not result in major damage to the concrete. In terms of durability, these cracks can represent a considerable reduction in the design life of the elements and also compromise the appearance of the structure. Deep cracks, unlike surface cracks, can damage the structure even more due to the possibility of water infiltration.

Dr.D.SENTHIL KUMARAN, M.E., Ph.D., (NUS)
Principal
SSM Institute of Engineering and Technology
Kuttathupatti Village, Sindalagundu (Po),
Palani Road, Dindigul 624 002

We Claim:

1. Most of the pathological manifestations in buildings are due to flaws in the execution and/or lack of quality control of the materials, which always tend to leave the concrete exposed to deleterious agents. In order to avoid the corrosion of the reinforcements and to prolong the useful life of the structures, the influences of the water/cement ratio (w/c) and the curing time in the carbonation process were evaluated.
2. For this, six beams with dimensions of 0.20 x 0.50 x 0.50 m were produced, divided into two groups with different w/c ratios and curing times.
3. The evaluation of the carbonation front was performed using the model of Tuutti (1982) and CEB Bulletin 34 (2006) and CEB Bulletin 55 (2010), and environmental factors were monitored since the beams were molded.

Dated this 27th day of August, 2022

Signature(s):

1.	
2.	RKPandey
3.	
4.	Rolly
5.	

...tute of Engineering and Techn...

Dr.D.SENTHIL KUMARAN, M.E.,Ph.D.,(NUS)
Principal
SSM Institute of Engineering and Technology
Kuttathupatti Village, Sindalagundu (Po),
Palani Road, Dindigul - 624 002.

6.	
7.	
8.	
9.	
10.	

Applicant(s):

1.	Dr. S. Sriram
2.	Dr. Rakesh Kumar Pandey
3.	Dr. Shubhlakshmi Tiwari
4.	Mrs. Rolly vaishnav
5.	Mr. Himanshu Namdeo
6.	Mr. M. P. Karthik
7.	Dr. Sumit Gandhi
8.	Mr. Arvind Viswakarma
9.	Mr. Mohit Kumar Prajapati
10.	Dr. Ravindra D Nalawade

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Dr.D.SENTHIL KUMARAN, M.E., Ph.D., (NUS)
Principal
SSM Institute of Engineering and Technology
Kuttathupatti Village, Sindalagundu (Po),
Palani Road, Dindigul - 624 002.

ABSTRACT

Effects of Water/Cement Ratio and Curing Time on the Carbonation Process of Reinforced Concrete Structures

[09] Reinforced concrete structures are subject to several forms of deterioration, one of which is carbonation – one of the main ones – which occurs when carbon dioxide present in the atmosphere reacts with calcium hydroxide. Most of the pathological manifestations in buildings are due to flaws in the execution and/or lack of quality control of the materials, which always tend to leave the concrete exposed to deleterious agents. In order to avoid the corrosion of the reinforcements and to prolong the useful life of the structures, the influences of the water/cement ratio (w/c) and the curing time in the carbonation process were evaluated. For this, six beams with dimensions of 0.20 x 0.50 x 0.50 m were produced, divided into two groups with different w/c ratios and curing times. The evaluation of the carbonation front was performed using the model of Tuutti (1982) and CEB Bulletin 34 (2006) and CEB Bulletin 55 (2010), and environmental factors were monitored since the beams were molded. In addition to the w/c ratio and curing time, the most influential parameter on the carbonation front is cement consumption. The higher the w/c ratio, the shorter the curing time and cement consumption, the higher the carbonation rate.

Accompanied Drawing **[FIG. 1] [FIG. 2][FIG. 3] [FIG. 4][FIG. 5] [FIG. 6] [FIG. 7] [FIG. 8][FIG. 9] [FIG. 10][FIG. 11] [FIG. 12][FIG. 13][FIG. 14][FIG. 15]**

Dated this 27th day of August, 2022

Signature(s):

1.	

Dr.D.SENTHIL KUMARAN, M.E., Ph.D., (NUS)
Principal
SSM Institute of Engineering and Technology
Kuttathupatti Village, Sindalagundu (Po),
Palani Road, Dindigul - 624 002.

2.	
3.	
4.	Rolly
5.	
6.	
7.	
8.	
9.	
10.	

Applicant(s):

1.	Dr. S. Sriram
2.	Dr. Rakesh Kumar Pandey
3.	Dr. Shubhlakshmi Tiwari
4.	Mrs. Rolly vaishnav
5.	Mr. Himanshu Namdeo
6.	Mr. M. P. Karthik
7.	Dr. Sumit Gandhi
8.	Mr. Arvind Viswakarma
9.	Mr. Mohit Kumar Prajapati
10.	Dr. Ravindra D Nalawade

Dr.D.SENTHIL KUMARAN, M.E., Ph.D., (NUS)
Principal
SSM Institute of Engineering and Technology
Kuttathupatti Village, Sindalagundu (Po),
Palani Road, Dindigul 624 002.

FORM 3

THE PATENTS ACT,
1970 (39 of 1970)
and
THE PATENTS RULES, 2003

STATEMENT AND UNDERTAKING UNDER SECTION 8

(See section 8; Rule 12)

1. Name of the applicant(s).	I/We, Dr. S. Sriram et al., all are citizen of India, Address of one of the Applicant: Assistant Professor, Faculty of Engineering and Technology, Assam Down Town University, Sankar Madhab Path, Gandhi Nagar, Panikhaiti, Guwahati, Assam, India Pincode - 781026.
2. Name, address and nationality of the joint applicant.	(i) that I/We have not made any application for the same/substantially the same invention outside India Or ~~(ii) that I/We who have made this application No… dated alone/jointly with ………………………, made for the same/ substantially same invention, application(s) for patent in the other countries, the particulars of which are given below:~~

Name of the Country	Date of Application	Application No.	Status of the Application	Date of Publication	Date of grant
-	-	-	-	-	-

3. Name and address of the assignee	(iii) that the rights in the application(s) has/have been assigned to ……………… none …………………… …………………………………………………………… ………………………… that I/We undertake that upto the date of grant of the patent by the Controller, I/We would keep him informed in writing the details regarding corresponding applications for patents filed outside India within six months from the date of filing of such application.

Dated this 28th day of August, 2022

DINDIGUL-624 002 • SSM Institute of Engineering and Technology

Dr.D.SENTHIL KUMARAN, M.E., Ph.D., (NUS)
Principal
SSM Institute of Engineering and Technology
Kuttathupatti Village, Sindalagundu (Po),

4. To be signed by the applicant or his authorized registered patent agent.	**Signature:**
5. Name of the natural person who has signed.	Dr. S. Sriram et. al. **Name of the Applicant(s)**
	To The Controller of Patents, The Patent Office, at Kolkata
Note.- Strike out whichever is not applicable;	

Dr.D.SENTHIL KUMARAN, M.E., Ph.D., (NUS)
Principal
SSM Institute of Engineering and Technology
Kuttathupatti Village, Sindalagundu (Po),
Palani Road, Dindigul - 624 002.

FORM- 5
THE PATENTS ACT, 1970
(39 of 1970)
&
The Patents Rules, 2003
DECLARATION AS TO INVENTORSHIP
[See Section 10(6) and Rule 13(6)]

1. NAME OF THE APPLICANT(S)

I/We, Dr. S. Sriram et al., all are citizen of India, Address of one of the Applicant: Assistant Professor, Faculty of Engineering and Technology, Assam Down Town University, Sankar Madhab Path, Gandhi Nagar, Panikhaiti, Guwahati, Assam, India. Pincode - 781026.

hereby declare that the true and first inventor(s) of the invention disclosed in the complete specification filed in pursuance of ~~my~~ / our application numbered ____________ dated 27-08-22 ~~is~~/are

2. INVENTOR(S)

(a) NAME	(b) NATIONALITY	(c) ADDRESS
1. Dr. S. Sriram	INDIAN	Assistant Professor, Faculty of Engineering and Technology, Assam Down Town University, Sankar Madhab Path, Gandhi Nagar, Panikhaiti, Guwahati, Assam, India. Pincode - 781026
2. Dr. Rakesh Kumar Pandey	INDIAN	Associate Professor, Department of Civil Engineering, MATS University Raipur, India-493441
3. Dr. Shubhlakshmi Tiwari	INDIAN	Associate Professor and Head of Department, Department of Civil Engineering, Chouksey Engineering College, Bilaspur, NH49 Lalkhadan Bilaspur 495001
4. Mrs. Rolly vaishnav	INDIAN	Assistant professor, Department of Civil Engineering Chouksey Engineering College, Bilaspur, NH49 Lalkhadan Bilaspur 495001
5. Mr. Himanshu Namdeo	INDIAN	Assistant professor, Department of Civil Engineering, Chouksey Engineering College, Bilaspur, NH49 Lalkhadan

DINDIGUL-624 002. * SSM Institute of Engineering and Technology

Dr.D.SENTHIL KUMARAN, M.E., Ph.D., (NUS)
Principal
SSM Institute of Engineering and Technology
Kuttathupatti Village, Sindalagundu (Po),
Palani Road, Dindigul - 624 002.

		Bilaspur 495001
6. Mr. M. P. Karthik	INDIAN	Assistant Professor, Department of Civil Engineering, SSM Institute of Engineering and Technology, Palani Highway, Sindalagundu Post, Dindigul – 624002.
7. Dr. Sumit Gandhi	INDIAN	Associate Professor and Head of Department, Department of Civil Engineering, Jaypee University of Engineering and Technology, Guna.
8. Mr. Arvind Viswakarma	INDIAN	Assistant Professor, Department of Civil Engineering, Oriental University, Indore - 453555
9. Mr. Mohit Kumar Prajapati	INDIAN	Faculty, Department of Civil Engineering, School of Engineering and Technology, Vikram University, Ujjain, Madhya Pradesh, 456010
10. Dr. Ravindra D Nalawade	INDIAN	Faculty, Department of Civil Engineering, AISSMS College of Engineering, Pune - 411001

~~3. DECLARATION TO BE GIVEN WHEN THE APPLICATION IN INDIA IS FILED BY THE APPLICANT(S) IN THE CONVENTION COUNTRY: -~~

N.A.

~~We the applicant(s) in the convention country hereby declare that our right to apply for a patent in India is by way of assignment from the true and first inventor(s).~~

Dated this 27th day of August, 2022

Dr. S. Sriram et al.
Applicant(s)

To,
The Controller of Patents
The Patent Office, Kolkata

Dr.D.SENTHIL KUMARAN, M.E., Ph.D., (NUS)
Principal
SSM Institute of Engineering and Technology
Kuttathupatti Village, Sindalagundu (Po),
Palani Road, Dindigul - 624 002.

FORM 9 THE PATENT ACT, 1970 (39 of 1970) & THE PATENTS RULES, 2003 **REQUEST FOR PUBLICATION** [See section 11A (2) rule 24A]
I/We **Dr. S. Sriram,Dr. Rakesh Kumar Pandey,Dr. Shubhlakshmi Tiwari,Mrs. Rolly vaishnav,Mr. Himanshu Namdeo,Mr. M. P. Karthik,Dr. Sumit Gandhi,Mr. Arvind Viswakarma,Mr. Mohit Kumar Prajapati,Dr. Ravindra D Nalawade** hereby request for early publication of my/our [Patent Application No.] TEMP/E-1/56165/2022-KOL
Dated **28/08/2022 00:00:00** under section 11A(2) of the Act.
Dated this(Final Payment Date):------------ Signature Name of the signatory
To, The Controller of Patents, The Patent Office, At Kolkata

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SSM Institute of Engineering and Technology, Dindigul

Dr.D.SENTHIL KUMARAN, M.E., Ph.D., (NUS)
Principal
SSM Institute of Engineering and Technology
Kuttathupatti Village, Sindalagundu (Po),
Palani Road, Dindigul - 624 002.