Assessment of Corrosion Inhibiting Efficiency of Microbes Induced Concrete

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Abstract. The study present in this paper reveals the corrosion inhibiting efficiency of M25 grade concrete induced with Sporosarcina pasteurii bacteria. The accelerated corrosion induced crack method is applied on reinforced bacterial concrete which is the modified philosophy of constant voltage technique. In the current investigation, for different cover thicknesses considered, total time required for charge passed until full longitudinal crack occurs along the cover thickness due to corrosion of steel reinforcement in concrete specimens are measured using which Charge Deterioration Factors (ChDFs) are evaluated for bacterial reinforced concrete beams made with various cell concentrations of Sporosarcina pasteurii bacteria. It was established that beams made with cell concentration of 10^5 cells/ml of mixing water offers superior corrosion inhibition ability as time taken to form full length longitudinal crack is more than in other beams made with 10^3 cells/ml, 10^4 cells/ml and 10^6 cells/ml cell concentration of bacteria chosen for the study.

1. Introduction

Concrete is inherently offers better resistance to corrosion of rebars embedded inside it except in very harsh saline environments. If the concrete is induced with Sporosarcina pasteurii bacteria during mixing stage, will contribute to more enhanced corrosion resistance capacity due to bio-mineralization mechanism during microbial metabolic activity. In this paper, an attempt has been made to measure the corrosion resistance in bacterial concrete specimens with four different thicknesses of covers using the impressed constant voltage technique. It is very labor intensive and time taking experiment with a fabricated setup. It is observed that the incorporation of bacteria into concrete helps to protect concrete against the chloride-induced corrosion of steel reinforcement by reducing its permeability, particularly for chloride-ion transportation, and increasing the impermeability of the concrete considerably.

Methodology

Various bacterial cell count of Sporosarcina pasteurii used are 10^3 cells/ml, 10^4 cells/ml, 10^5 cells/ml and 10^6 cells/ml. The nutrients used for the growth and cultivation of bacterial culture comprises of urea (20 g/l), sodium bi-carbonate (2.12 g/l), ammonia chloride (10 g/l) and calcium chloride (25 g/l).

Sporosarcina pasteurii is an alkaliphilic soil bacterium is introduced into concrete in suspension during mixing. Microbiologically Induced calcite precipitation (Bio-mineralization) is the process in which Sporosarcina pasteurii releases urease enzyme which hydrolyze the urea nutrient to form carbon dioxide and ammonia. Carbon dioxide reacts with calcium nutrients to produce calcium carbonate minerals which will fill up the micro and macro pores present in the concrete arresting the continuous water paths present. Ammonia will help concrete to maintain its pH so that passive layer can be formed on rebars as protective surface layer.

A total of 10 beams of dimensions 150 X 150 X 500 mm are cast and tested after 28 days of normal curing. The beams have the reinforcement of 10 mm diameter HYSD bar at different effective covers ranging from 10 mm to 40 mm at all four corners of each beam.

Accelerated Corrosion Test

Due to the expansive nature of corrosion products in rebar concrete beams of M25 grade, corrosion-induced cracks are generated at the interface between the rebars and its surrounding concrete resulting in cracking and spalling of cover. To simulate this corrosion process in a typical seawater environment. The beam specimens were submerged into artificial sea water solution prepared in the laboratory as per ASTM D 1141 – 1998 (Sodium chloride 24.53 g/lit, Magnesium chloride 5.2 g/lit, Sodium sulphate 4.09 g/lit, Calcium chloride 1.16 g/lit, Potassium chloride 0.695 g/lit). The specimens were corroded using an electrochemical accelerated corrosion technique that involved keeping a constant voltage of 20V through the specimens to accelerate the oxidation process in a 3.5% saline solution. When Steel rebars are corroded electrochemically eventually leads to the expansion of rebars inducing cracks in the cover of the concrete. Time taken to induce complete crack along the length of beam is computed to estimate the corrosion resistance ability of bacterial concrete. This test procedure is inspired from the standard ASTM G109. Corrosion in rebars can be artificially induced either by providing constant current through rebars or by keeping voltage constant. In this test the beams reinforced with 10 mm diameter rebars with different effective covers are casted as shown in Fig. below.

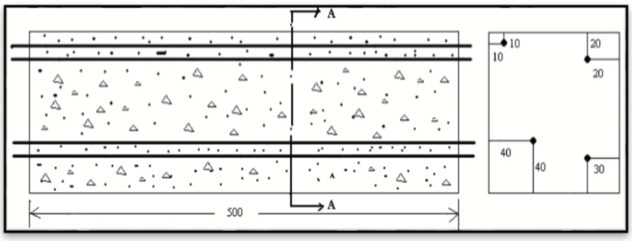

Fig.1. Schematic diagram of reinforced beam used for the test

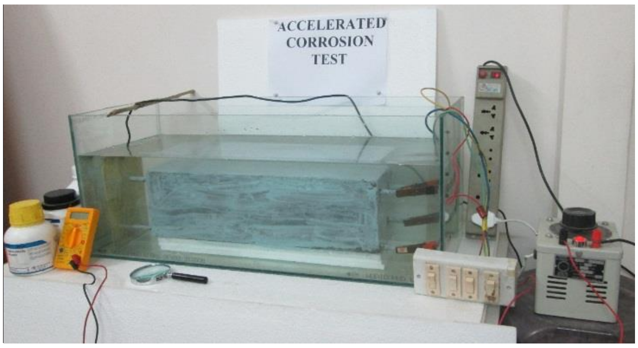

Fig. 2. Setup for the Accelerated Corrosion test

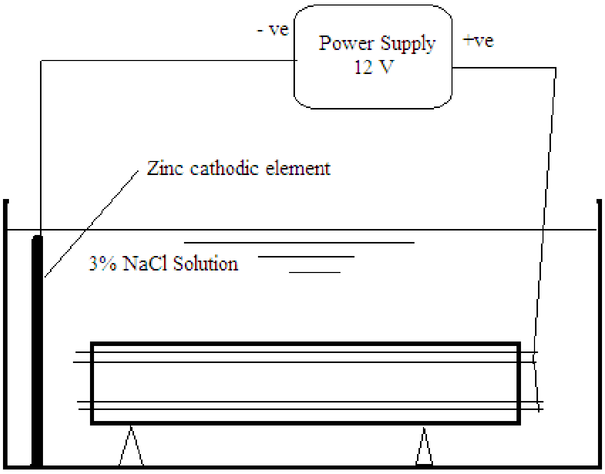

Fig. 3. Schematic diagram of Accelerated corrosion test setup

The test specimens concrete reinforced beams has different effective covers of 10 mm, 20 mm, 30 mm and 40 mm at all four corners. The test specimens are immersed in saline watered glass tub. All the extended rebars are connected to the power supply in parallel and anodic current is passed at a constant voltage of 20 V. For every 12 hrs. interval, the half-cell potentials are recorded for all the rebars. Time and length of the crack along the beam was observed frequently till the crack is formed longitudinally (500 mm). The experimental set up is shown in Fig..

Inspired from ASTM C 666 – 1997, the Charge Deterioration Factors are evaluated for every 12 hours based on the relative charge.

Charge Deterioration Factor (ChDF) = rCh (N/M)

Where, rCh = Relative Charge (%)

N = Time at which ChDF is to be evaluated.

M = Time taken for complete crack in reference reinforced beam

B1 = Normal M25 grade concrete reinforced beam

B2 = M25 grade bacterial concrete reinforced beam made with cell concentration of 10^3 cells/ml

B3 = M25 grade bacterial concrete reinforced beam made with cell concentration of 10^4 cells/ml

B4 = M25 grade bacterial concrete reinforced beam made with cell concentration of 10^5 cells/ml

B5 = M25 grade bacterial concrete reinforced beam made with cell concentration of 10^6 cells/ml

Accelerated Corrosion Test Results

Based on the experimental investigations, the test results are presented as follows-

The table 1 and Fig. 6 presents time taken for formation of full crack due corrosion along the length of beams for beams with various cells of bacteria and compared with beams without bacteria. Tables 2-5 presents relative charge (rCh) and charge deterioration factors (ChDF) for various concrete cover thickness.

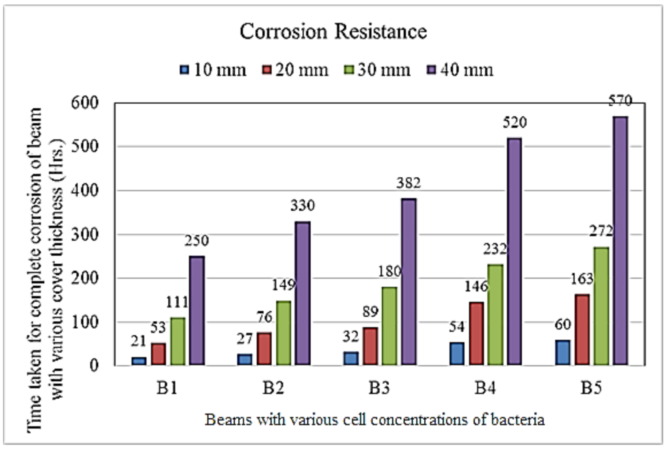

Fig. 4. Time taken for complete corrosion of rebar in beams with various concrete cover thickness *(Time taken for full crack to occur longitudinally along the length of beams with different cover thickness)*

Table 1. Relative Charge (rCh) and Charge Deterioration Factors (ChDF) for 10mm Cover

Test duration	Corrosion indicators	Relative Charge (rCh) and Charge Deterioration Factors (ChDF) for 10mm effective cover				
		B1	B2	B3	B4	B5
0	rCh	0.00	0.00	0.00	0.00	0.00
	ChDF	0.00	0.00	0.00	0.00	0.00
12	rCh	57.14	44.44	37.50	20.00	22.22
	ChDF	1.20	0.94	0.79	0.42	0.47
24	rCh	100.00	88.89	75.00	40.00	44.44
	ChDF	4.81	3.74	3.16	1.68	1.87
36	rCh		100.00	100.00	60.00	66.67
	ChDF		8.42	7.11	3.79	4.21
48	rCh				80.00	88.89
	ChDF				6.74	7.49
60	rCh				100.00	100.00
	ChDF				10.53	11.70

Table 2. Relative Charge and Charge Deterioration Factors for 20mm Cover

Test duration	Corrosion indicators	Relative Charge (rCh) and Charge Deterioration Factors (ChDF) for 20 mm Effective Cover				
		B1	B2	B3	B4	B5
0	rCh	0.00	0.00	0.00	0.00	0.00
	ChDF	0.00	0.00	0.00	0.00	0.00
12	rCh	22.64	15.79	13.48	7.36	8.22
	ChDF	0.48	0.33	0.28	0.15	0.17
24	rCh	45.28	31.58	26.97	14.72	16.44
	ChDF	1.91	1.33	1.14	0.62	0.69
36	rCh	67.92	47.37	40.45	22.09	24.66
	ChDF	4.29	2.99	2.55	1.39	1.56
48	rCh	90.57	63.16	53.93	29.45	32.88
	ChDF	7.63	5.32	4.54	2.48	2.77
60	rCh	100.00	78.95	67.42	36.81	41.10
	ChDF	11.92	8.31	7.10	3.87	4.33
72	rCh		94.74	80.90	44.17	49.32
	ChDF		11.97	10.22	5.58	6.23
84	rCh		100.00	94.38	51.53	57.53
	ChDF		16.29	13.91	7.59	8.48
96	rCh			100.00	58.90	65.75
	ChDF			18.17	9.92	11.07
108	rCh				66.26	73.97
	ChDF				12.55	14.02
120	rCh				73.62	82.19
	ChDF				15.50	17.30

132	rCh				80.98	90.41
	ChDF				18.75	20.94
144	rCh				88.34	98.63
	ChDF				22.32	24.92
156	rCh				95.71	100.00
	ChDF				26.19	29.24
168	rCh				100.00	
	ChDF				30.38	

Table 3. Relative Charge and Charge Deterioration Factors for 30mm Cover

Test duration	Corrosion indicators	Relative Charge (rCh) and Charge Deterioration Factors (ChDF) for 30 mm effective cover				
		B1	B2	B3	B4	B5
0	rCh	0.00	0.00	0.00	0.00	0.00
	ChDF	0.00	0.00	0.00	0.00	0.00
12	rCh	10.81	8.05	6.67	4.41	5.17
	ChDF	0.23	0.17	0.14	0.09	0.11
24	rCh	21.62	16.11	13.33	8.82	10.34
	ChDF	0.91	0.68	0.56	0.37	0.44
36	rCh	32.43	24.16	20.00	13.24	15.52
	ChDF	2.05	1.53	1.26	0.84	0.98
48	rCh	43.24	32.21	26.67	17.65	20.69
	ChDF	3.64	2.71	2.25	1.49	1.74
60	rCh	54.05	40.27	33.33	22.06	25.86
	ChDF	5.69	4.24	3.51	2.32	2.72
72	rCh	64.86	48.32	40.00	26.47	31.03
	ChDF	8.19	6.10	5.05	3.34	3.92
84	rCh	75.68	56.38	46.67	30.88	36.21
	ChDF	11.15	8.31	6.88	4.55	5.34
96	rCh	86.49	64.43	53.33	35.29	41.38
	ChDF	14.57	10.85	8.98	5.94	6.97
108	rCh	97.30	72.48	60.00	39.71	46.55
	ChDF	18.44	13.73	11.37	7.52	8.82
120	rCh	100.00	80.54	66.67	44.12	51.72
	ChDF	22.76	16.96	14.04	9.29	10.89
132	rCh		88.59	73.33	48.53	56.90
	ChDF		20.52	16.98	11.24	13.18
144	rCh		96.64	80.00	52.94	62.07
	ChDF		24.42	20.21	13.37	15.68
156	rCh		100.00	86.67	57.35	67.24
	ChDF		28.65	23.72	15.70	18.40
168	rCh			93.33	61.76	72.41
	ChDF			27.51	18.20	21.34
180	rCh			100.00	66.18	77.59
	ChDF			31.58	20.90	24.50
192	rCh				70.59	82.76
	ChDF				23.78	27.88
204	rCh				75.00	87.93
	ChDF				26.84	31.47
216	rCh				79.41	93.10
	ChDF				30.09	35.28
228	rCh				83.82	98.28
	ChDF				33.53	39.31
240	rCh				88.24	100.00
	ChDF				37.15	43.56
252	rCh				92.65	
	ChDF				40.96	
264	rCh				97.06	
	ChDF				44.95	
276	rCh				100.00	

ChDF	49.13

Table 4. Relative Charge and Charge Deterioration Factors for 40mm Cover

Test duration	Corrosion indicators	Relative Charge (rCh) and Charge Deterioration Factors (ChDF) for 40 mm effective cover				
		B1	B2	B3	B4	B5
0	rCh	0.00	0.00	0.00	0.00	0.00
	ChDF	0.00	0.00	0.00	0.00	0.00
12	rCh	4.80	3.64	3.14	2.11	2.31
	ChDF	0.10	0.08	0.07	0.04	0.05
24	rCh	9.60	7.27	6.28	4.21	4.62
	ChDF	0.40	0.31	0.26	0.18	0.19
36	rCh	14.40	10.91	9.42	6.32	6.92
	ChDF	0.91	0.69	0.60	0.40	0.44
48	rCh	19.20	14.55	12.57	8.42	9.23
	ChDF	1.62	1.22	1.06	0.71	0.78
60	rCh	24.00	18.18	15.71	10.53	11.54
	ChDF	2.53	1.91	1.65	1.11	1.21
72	rCh	28.80	21.82	18.85	12.63	13.85
	ChDF	3.64	2.76	2.38	1.60	1.75
84	rCh	33.60	25.45	21.99	14.74	16.15
	ChDF	4.95	3.75	3.24	2.17	2.38
96	rCh	38.40	29.09	25.13	16.84	18.46
	ChDF	6.47	4.90	4.23	2.84	3.11
108	rCh	43.20	32.73	28.27	18.95	20.77
	ChDF	8.19	6.20	5.36	3.59	3.94
120	rCh	48.00	36.36	31.41	21.05	23.08
	ChDF	10.11	7.66	6.61	4.43	4.86
132	rCh	52.80	40.00	34.55	23.16	25.38
	ChDF	12.23	9.26	8.00	5.36	5.88
144	rCh	57.60	43.64	37.70	25.26	27.69
	ChDF	14.55	11.02	9.52	6.38	7.00
156	rCh	62.40	47.27	40.84	27.37	30.00
	ChDF	17.08	12.94	11.18	7.49	8.21
168	rCh	67.20	50.91	43.98	29.47	32.31
	ChDF	19.81	15.00	12.96	8.69	9.52
180	rCh	72.00	54.55	47.12	31.58	34.62
	ChDF	22.74	17.22	14.88	9.97	10.93
192	rCh	76.80	58.18	50.26	33.68	36.92
	ChDF	25.87	19.60	16.93	11.35	12.44
204	rCh	81.60	61.82	53.40	35.79	39.23
	ChDF	29.20	22.12	19.11	12.81	14.04
216	rCh	86.40	65.45	56.54	37.89	41.54
	ChDF	32.74	24.80	21.43	14.36	15.74
228	rCh	91.20	69.09	59.69	40.00	43.85
	ChDF	36.48	27.64	23.87	16.00	17.54
240	rCh	96.00	72.73	62.83	42.11	46.15
	ChDF	40.42	30.62	26.45	17.73	19.43
252	rCh	100.00	76.36	65.97	44.21	48.46
	ChDF	44.56	33.76	29.17	19.55	21.43
264	rCh		80.00	69.11	46.32	50.77
	ChDF		37.05	32.01	21.45	23.51
276	rCh		83.64	72.25	48.42	53.08
	ChDF		40.50	34.98	23.45	25.70
288	rCh		87.27	75.39	50.53	55.38
	ChDF		44.10	38.09	25.53	27.98
300	rCh		90.91	78.53	52.63	57.69
	ChDF		47.85	41.33	27.70	30.36
312	rCh		94.55	81.68	54.74	60.00
	ChDF		51.75	44.71	29.96	32.84
324	rCh		98.18	84.82	56.84	62.31
	ChDF		55.81	48.21	32.31	35.42
336	rCh		100.00	87.96	58.95	64.62
	ChDF		60.02	51.85	34.75	38.09
348	rCh			91.10	61.05	66.92
	ChDF			55.62	37.27	40.86
360	rCh			94.24	63.16	69.23
	ChDF			59.52	39.89	43.72
372	rCh			97.38	65.26	71.54

	ChDF	63.55	42.59	46.69
384	rCh	100.00	67.37	73.85
	ChDF	67.72	45.39	49.75
396	rCh		69.47	76.15
	ChDF		48.27	52.91
408	rCh		71.58	78.46
	ChDF		51.24	56.16
420	rCh		73.68	80.77
	ChDF		54.29	59.51
432	rCh		75.79	83.08
	ChDF		57.44	62.96
444	rCh		77.89	85.38
	ChDF		60.68	66.51
456	rCh		80.00	87.69
	ChDF		64.00	70.15
468	rCh		82.11	90.00
	ChDF		67.41	73.89
480	rCh		84.21	92.31
	ChDF		70.91	77.73
492	rCh		86.32	94.62
	ChDF		74.50	81.67
504	rCh		88.42	96.92
	ChDF		78.18	85.70
516	rCh		90.53	99.23
	ChDF		81.95	89.83
528	rCh		92.63	100.00
	ChDF		85.81	94.06
540	rCh		94.74	
	ChDF		89.75	
552	rCh		96.84	
	ChDF		93.78	
564	rCh		98.95	
	ChDF		97.91	
576	rCh		100.00	
	ChDF		100.00	

Cracks at concrete cover level indicates the scale of corrosion in the rebars. Occurrence of full crack at concrete cover level along the length of beam confirms 100 percent corrosion in that rebar. Time taken for occurrence of full crack at concrete cover level along the length of beam demonstrates the corrosion inhibitive ability of bacterial concrete beams of various cover thickness. From the test results 10^5 cell concentration of bacterial concrete beams fared well in protecting the steel reinforcement in concrete. At any instant of test duration, charge passed through reinforced bacterial concrete beams is less than normal reinforced beams where no bacteria is used. This indicates that flow of electrons is less in bacterial concrete beams so is the rate of corrosion. More charge passed indicates more passage of electrons so is the more probability of corrosion. Time taken for 100% passage of charge through rebars in concrete beams incorporated with optimum cell concentration of bacteria is more compared to normal beams which means bacterial concrete beams will take more time to corrode. Reinforced concrete beams admixed with optimum cell concentration took relatively more time to allow 100% charge pass through it for also cover thicknesses considered. So possible inception of corrosion in bacteria incorporated reinforced concrete beams is very low when compared to normal beams.

At any instant of test duration, Charge deterioration factors will indicate the magnitude of deterioration caused due to corrosion in the beams. Charge deterioration factors will be more in normal reinforced beams. Reinforced bacterial concrete beams has less charge deterioration factors at all cover thicknesses considered. This may be due to dense microstructure of bacteria induced concrete.

8. Conclusions

1. The time of total charge passing till full crack failure for different effective covers considered is more for bacterial concrete than the normal concrete. This increase in total time for full crack to occur is observed in 10^5 bacterial cell concentration incorporated beams.
2. The time of total charge passing at failure in bacterial concrete is more because beam specimens did not develop any fissures or micro cracks as they did not expand when immersed in natural sea water due to calcite precipitation layer on the surface of beams.
3. The "Charge Deterioration Factors" at any given time of full crack failure for different effective covers considered is less for bacterial concrete than the normal concrete.

It is concluded that that bacterial concrete will have the higher life compared to normal concrete. Bacterial concrete will have high life than the normal concrete because calcite precipitate crystals impermeable the concrete specimens and resists the harmful solutions into the concrete there by decreasing the deleterious effects they may cause.

9. References

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