An Experimental Study on Bio Mimicry Concrete by using Bacillus Subtilis & Sodium Polyacrylate

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Abstract

The formation of a microcrack in concrete is common, which leads to costly maintenance. The concrete needs to be repaired. Bio-mimicry techniques give favourable results in sealing micro-crack & heal this crack in the concrete. To overcome these situations, self-healing techniques are adopted. By the adding of lime producing bacteria along with calcium lactate result in calcite precipitation in concrete. Sealing work explores the use of Super Absorbent Polymer in concrete with proper mix design. Various properties, including the viscosity, the curing time, the swelling capacity and cross-linking efficiency, has been evaluated. A continuous hydration process in concrete can seal up the freshly formed microcrack. Bacteria bacillus subtilis which can produce lime, is added to the healing agent to seal the freshly formed micro-cracks by CaCo3 precipitation. The increase of durability, compressive strength and reduction of permeability in concrete is attained. The ability to heal and seal the cracks in concrete was observed. Maintaining pH under favourable conditions, the permeability of concrete, crack healing capacity of concrete was observed.

Keywords: - *bio-mimicry, self-healing, super absorbent polymer, bacillus subtilis, calcium lactate, sodium polyacrylate;*

INTRODUCTION

Bio-mimicry is an approach to innovative solutions to human challenges by copying nature's time-tested patterns and processes.

Plants and animals can seal and heal wounds. In all plants and animals examined, firstly, a self-sealing phase and secondly, a self-healing phase can be identified. In plants, rapid self-sealing prevents the plants from dry and from infection by pathogenic germs. This gives time for the subsequent self-healing of the injury, which in addition to wound closure, also results in the (partly) restoration of mechanical properties of the plant organ. Different functional principles were transferred into bio-inspired self-repairing materials based on various self-sealing and self-healing processes in plants. The connecting link between the biological model and the technical application is an abstraction

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describing the underlying functional principle of the biological model, which can be, for example, an analytical model or a numerical model. In cases where mainly physical-chemical processes are involved, a transfer is especially promising. This process of structure from above can be used to mimic the design of the skin essentially.

Plants and animals can seal and heal wounds. Same with this concept, our structure is a body and crack in structure is wounds. However, concrete is likely to break when exposed to structural loading or non-structural factors such as thermal effects, shrinkage and physiochemical reactions. Self-healing and self-repair is a common theme in biological systems from trees to human skin. The less severe the damage is to an organism, the easier it is for the organism to repair itself and for the repair to be solid and long-lasting. Cracking in concrete occurs commonly due to the relatively low tensile strength. Cracking causes seepage and affects water tightness, a serious serviceability requirement for many structures such as basements, retaining walls, reservoirs, dams, tunnels, pipelines, and waste repositories. Now compare structure with our body when wounds occur, our blood cells feel this wound as in structure when a crack develops, it can be handled by itself using bacteria and SAP materials.

HISTORY

The ancient Romans used a form of lime mortar that has been found to have self-healing properties. A Dutch scientist has invented self-healing concrete, a product that could save money and work in the long run despite its higher initial cost. HendrikJonkers, a microbiologist at the Delft University of Technology, was one of 15 finalists in the European Inventor Award of 2015 for his invention. He's fielded queries worldwide for the bio-mimicry product, where nature's models are examined to find designs and applications that solve human problems. With a background in marine biology and his PhD in microbiology, Jonkers was familiar with how bacteria behave.

Through research, Jonkers chose Bacillus pseudofirmus and Sporosarcinapasteurii bacteria that biologically produce limestone and are found near volcanoes. One positive side effect is that the bacteria consume oxygen and prevent the internal corrosion of reinforced concrete. As well, the bacteria can survive for 200 years. This section comprises some of the kinds of literature used for physiological signal measurement techniques developed by various researchers using non-invasive methods with their importance.

LITERATURE

Vanessa Giaretton Cappellesso, Deividi Maurente Gomes da Silva [1] has published a paper on Self-Healing concrete in Cementitious Matrix with Different Water/Cement Ratios and Crack Opening Age- In this paper, Concrete elements are subject to cracking, which can be an access point for harmful agents that can trigger pathological bacteria reducing the service life of structures. Autogenously self-healing can be defined as a natural process in which the sealing of these cracks occurs without the stimulation of external agents, meaning without different materials being added to the mixture. The widths of the crack created are larger for lower water/cement ratios and older age of crack opening. Regardless of the cracking age, concretes achieve stability in the processes that can contribute to self-healing between 80 days and 90 days after casting the specimens. The concretes analyzed demonstrated lower recovery by the

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ultrasonic pulse propagation velocity test but presented a considerable amount of product formed when analyzed with the optical microscopy.

Hassan Amer Algaifi, Suhaimi Abu Bakar, Abdul Rahman Mohd. Sam, Ahmad Razin Zainal Abidin, Shafinaz Shahir, Wahid Ali Hamood AL-Towayti, [2] has published a paper on Numerical modelling for crack self-healing concrete by microbial calcium carbonate- In this study, they developed a model that can predict the bio concrete crack-healing relatively well. A crack width of 0.4 mm was healed at 70 days compared to 60 days in the model. With the increase of urea hydrolysis, more calcium carbonate could be formed. The hydrolysis of urea induces the diffusive transport mechanism to the boundary. The model was found to apply to highly reactive systems such as those proposed for engineering applications of MICP. Moreover, scanning electron microscopy (VP-SEM) with energy dispersive X-ray analysis (EDX) was used to verify the predicted crack healing results. Both showed a relatively high degree of similarity with a correlation coefficient of R = 0.99.

Abir Al-Tabbaa, Chrysoula Litina, Petros Giannaros, Antonios Kanellopoulos, Livia Souza [3] has published a paper on the First UK field application and performance of microcapsule-based self-healing concrete. In this study, they obtain the first large-scale field trial of microcapsule-based self-healing concrete in the UK. Microcapsules were developed and implemented in concrete on site. The self-healing process was demonstrated in both infield and laboratory assessments. Crack width and depth and permeability reduction, and strength recovery was achieved. They find Accelerated crack healing along the main crack of 49%, and 63% was evident as early as 14 days and 28 days for the microcapsule wall compared to 14% and 36%, respectively, for the control. The average crack depth was also seen to reduce by 8% and 39% after 14 days in the control and microcapsule walls, respectively, reaching a final 20% and 58% at the end of the monitoring period. These results were further confirmed by significant permeability recovery (almost greater than 2.5 orders of magnitude) for the microcapsule wall. A strength recovery of 25% was achieved in the microcapsule wall, achieving a 10% improvement over the control panel.

J. Feiteira, E. Gruyaert, N. De Belie [4] has published a paper on the Self-healing of moving cracks in concrete using encapsulated polymer precursors – In this study is based on low viscosity of precursors was critical to achieving effective sealing of cracks. A maximum crack widening of 50% to 100% was allowed before sealing was disrupted. Failure for non-foaming precursors occurred due to detachment from the crack walls. Foaming precursors failed due to the rupturing of foam cells. A maximum stiffness regains of 35% was achieved after healing. Out of the eight series tested, only the ones containing the precursor SLV led to complete healing. Regarding the regain of mechanical properties, the repair of bending stiffness was limited (35% at best), even for the series showing complete healing. This was due to the low stiffness of the cured polymers.

L. Coppola, D. Coffetti, E. Crotti [5] has published a paper on Innovative carboxylic acid waterproofing Admixture for self-sealing watertight concretes – in this present paper

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evaluates the performances of an innovative carboxylic acid-based admixture to improve concrete water tightness and self-sealing ability of the cement matrix. Results indicate that fumaric acid-based waterproofing admixture improves concrete water tightness. In particular, adding 1% by cement mass of the carboxylic polymer causes a reduction in the water penetration under the pressure of 7-day wet cured concrete by 50% compared to that of the corresponding reference concrete. The ability to seal cracks (400 um width) due to plastic shrinkage was also confirmed by Karsten tubes tests, optical microscopy and scanning electron microscope (SEM) test observations on cracked and sound concrete slabs.

Ping Yang, Yao-hui Liu, Shu-wen Gao [6] has published a paper on an Experiment on the sealing efficiency of carbon fibre composite grout under flowing conditions – they Investigated the most significant difficulty of grouting fractures under flowing condition was that the flowing easily washed out the slurry. To raise the sealing efficiency (SE) and dynamic flowing resistance of slurry, carbon fibre was added into the grout, and a new grout for the flowing water environment was provided. Contrast tests and Scanning electron microscope (SEM) tests were conducted to investigate the effect of carbon fibre. The result showed that the solidification velocity and dynamic flowing resistance increased with increased carbon fibre content due to the stochastic distribution and significant surface friction of carbon fibre. In addition, a series of orthogonal tests were conducted to investigate the effect of some factors on sealing efficiency (SE). The result showed that the SE decreased with the increase of initial flow speed and aperture width, and it increased with the rise in cement water ratio and additive content.

Moayyad Al-Nasra, [7] has published a paper on Self-sealing concrete mortar, concrete mortar mixed with a super absorbent polymer. This research uses superabsorbent polymer as an admixture to improve its water tightness properties, especially in concrete tanks, aeration basins, and retaining structures. Several samples have been prepared to study the effect of the superabsorbent polymer on the concrete strength and on the concrete capability to block the water flow. Concrete cubes, concrete beams, and concrete tension samples were prepared to study the concrete strength mixed with the superabsorbent polymer. Also, concrete short cylindrical samples were prepared to study the concrete ability to block the water flow. These cylindrical samples were intentionally broken into two approximately equal pieces to create an induced crack. The artificially cracked samples are then subjected to water pressure to study the concrete ability to stop the water flow through the induced concrete crack. Two kinds of water pressure are used in this research; the constant head and the falling head.

LeyangLv, Erik Schlangen, and Feng Xing [8] have published a paper on Self-Sealing Cementitious Materials by Using Water-Swelling Rubber Particles in Materials. This study developed the application of water-swelling rubber particles to provide the cracked concrete with a self-sealing function. The feasibility of applying water-swelling rubber particles and the influence of incorporating water-swelling rubber particles on the mechanical properties of concrete was investigated. The self-sealing efficiency of water-

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swelling rubber particles with different content and particle size was quantified through a permeability test. The sealing effect of the water swelling rubber particles was monitored by X-ray computed tomography. The experimental results show that by using 6% of these water swelling rubber particles as a replacement of aggregates in concrete, up to 64% and 61% decrease of water permeability was realized for 0.7 mm and 1.0 mm cracks. Furthermore, when the concrete cracks, the water swelling rubber particles can act as a crack-bridging filler, preventing the crack from fully separating the specimens in two pieces.

MATERIAL

- **CEMENT**

The cement of 53 grades will be used in this study: Ordinary Portland cement use is fresh and without any lumps. The cement used has been tested for various properties as per IS: 4031-1988 and found to be conforming to various specifications of IS: 12269-1987.

- **FINE AGGREGATE**

Natural River sand well-graded passing through a 4.75mm sieve will be used. Fine aggregate conformed to Indian Standard Specifications IS 383-1970.

- **COARSE AGGREGATE**

The size of the aggregate bigger than the 4.75 mm is called coarse aggregate. Crushed aggregate is with a size of 10-20 mm standard continuous grading is used. The sieve analysis of coarse aggregates is confirmed to be IS-10262.

- **SUPERABSORBENT POLYMER**

Twenty types of commercially available SAP were obtained, from which four will be selected and used for this study. The rest were rejected mainly because it was thought that their particle sizes and swelling properties were inappropriate for this application. The selected polymers were either polyacrylate or polyacrylate-co-acrylamide. The selected SAP is cross-linked sodium polyacrylate. This is in a white powder form with particle size ranging from several microns up to about 500μm.

TABLE I. Properties of Sap

	Properties of sodium polyacrylate		
	Item	**Specification**	**unit**
1	≤ Residual Monomer	150-300	PPM
2	≤ Moisture Content	6.0	%
3	PH Value	6.0-6.5	--
4	Particle size distribution	80-120 Mesh	%
5	Density	059~0.65	G/cm^3
6	Absorption Rate 0.9% NaCl Solution	≤10	S
7	Absorption in 0.9% NaCl Solution	≥54	g/g
8	Retention Capacity after Centrifugation	≤25	g/g
9	Absorption under pressure	≤26	0.3psi g/g
10	Appearance	White solid	

- **BACTERIA**

Bacillus subtilis is a facultative anaerobe bacterium. It is a gram-positive, alkaliphilic and alkali-tolerant, aerobic endospore-forming bacteria.

TABLE II. Properties of Bacteria

	Properties of Bacillus Subtilis		
	Specification	**Result Obtained**	**Limit as per specification**
1	Appearance	Complies	Off white to Brown Color occasionally Black Spec
2	Moisture	3.45 %	NMT 8 %
3	Odour	Complies	Normal Fermentation odour
4	Viable Cell Count	1000 Million cfu/g	NLT 1000 Million cfu/g
5	E.Coli	Passes the test	Should be Absent
6	Salmonella sp.	Salmonella sp.	Should be Absent

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MIX DESIGN

Studying the various properties of concrete, fresh concrete & hardened concrete is to design a concrete mix for particular strength.

Mix design can be defined as the process of selecting suitable ingredients of concrete & find out optimum proportions with the object of producing concrete of specific minimum strength & durability as economically as possible. The mix design is explained in the following section.

- Indian Standard method mix design
- Concrete Grade: M60
- Exposure: Mid
- Quality Control: Fair
- Size of aggregate: 10-20 mm
- Degree of workability: 0.95
- Cement : OPC 53 grade
- Sand zone: I
- Water content : 0.35-0.40 %
- Min Cement content : 419.4 kg/m3
- Sp. The gravity of cement: 3.15
- Sp. The gravity of coarse aggregate: 2.75
- Sp. The gravity of fine aggregate: 2.47

TABLE III Mix Design Quantity of Material Per M3 of Concrete

Material	Weight Basis (Kg)	Volume (m^3)
Water	0.364	153
Cement	1	419.4
Fly ash	0.419	104.86
Fine Aggregate	1.22	599.9
Coarse Aggregate	2.89	1127
Admixture	-	4.77

EXPERIMENTAL STUDY

The process of manufacturing quality concrete requires proper care exercised at every stage of the manufacture of concrete. We must know the good rules to be followed at each stage of producing concrete to produce good quality concrete.

WEIGH BATCHING

Weigh batching is the correct method of measuring materials. For concrete weigh batching system should be adopted. The use of a weight system in batching facilitates accuracy, flexibility & simplicity.

MIXING

After batching was done, a mixer of cement, sand, Fly ash, SAP/bacteria & aggregate were mixed thoroughly for 2 min. water was then added and missed for another 5 min. in mixes marked with calcium nitrate/calcium lactate was first dissolved in batch water before addition

PLACING & COMPACTION

The concrete must be placed systematically to yield optimum results: the safety care to be taken and the method adopted while placing concrete in moulds.

Compaction consists of rodding, ramming or tamping. Tamping is one of the usual & regular methods adopted in compacting where the thickness of concrete is comparatively less and the surface to be finished smooth and level.

CURING

By the hydration of cement particles: Curing can also be described as keeping the concrete moist and warm enough so that the hydration of cement can continue until the desired properties are developed to a sufficient degree to meet the service requirement. The casted cube and cylinders are immersed in water tanks, respectively, for 7 and 28 days.

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WORKABILITY OF CONCRETE

Slump test is the regular & commonly method of measuring workability/consistency of concrete, which can be done either in the laboratory or at site work. After the top layer has been full of tamped concrete is struck off level with a trowel and tamping road.

The mould is removed from the concrete immediately by rising it slowly and carefully in a vertical direction. This allows the concrete to subside. The subside is referred to as a slump of fresh concrete.

The value of slump= 95mm

COMPRESSIVE STRENGTH TEST& RESULT

The compression test is used to determine the hardness of cubical and cylindrical specimens of concrete. The strength of a concrete specimen depends upon cement, aggregate, bond, water-cement ratio, curing temperature, and age and size of the specimen. Cubes of size 15cm x 15cm x 15cm (as per IS: 10086-1982) should be cast.

Remove the specimen from the water after a specified curing time as per IS Standards and wipe out excess water from the surface. Take the dimension of the specimen to the nearest 0.2m. Clean the bearing surface of the testing machine. Place the specimen in the machine so that the load shall be applied to the opposite sides of the cube cast. Align the specimen centrally on the base plate of the machine. Rotate the movable portion gently by hand so that it touches the top surface of the specimen.

Apply the load gradually without shock and continuously. The specimen should be given sufficient time for hardening, and then it should be cured for 7 and 28 days. Compressive strength should be calculated by dividing the maximum load by the cross-sectional area.

Compressive Strength (N/mm2) =Ultimate load / C/S area of specimen.

TABLE IV Compressive Strength of Cube After 7 Days

No. of Percentage	SAP	Bacteria
5%	28.75	41.42
10%	25.66	34.18
15%	25.42	20.45

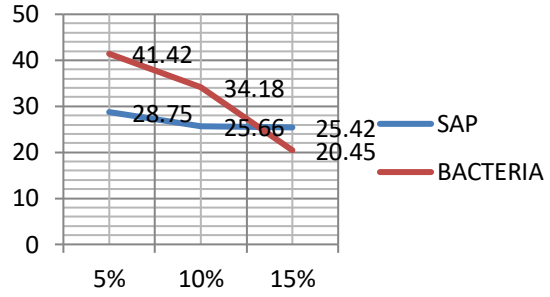


Fig. 1- Graph shows result after seven days of compression

Table V. Compressive Strength of Cube after 28 Days

No. of Percentage	SAP	Bacteria
5%	39.76	51.85
10%	30.20	49.41
15%	33.58	36.13

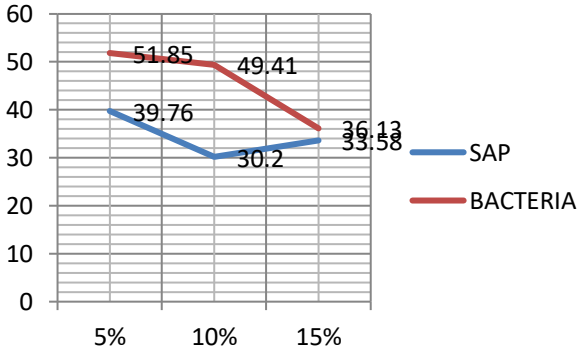


Fig.2- Graph shows result after 28 days of compression

CONCLUSION

The study proposed a model of concrete is used as an essential material in the construction industry. A bio mimic (self-sealing & self-healing) concrete is done by adding Bacillus subtilis bacteria &

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sodium polyacrylate SAP in concrete. Both materials affect the core of concrete because SAP in concrete can increase initial swelling and reduce its impact on strength. And by using Bacillus subtilis, it can grow in a curing tank when in contact with water to decrease the strength of concrete.

We have found out that after 28 days, compressive strength of the bacterial concrete with 5%, 10% and 15% of the addition of Bacillus subtilis as 51.85%, 49.41%, and 36.13 %, respectively. In the same way, we have found out that after 28 days, compressive strength of the bacterial concrete with 5%, 10% and 15% of the addition of sodium polyacrylate as 39.76%, 30.20%, and 33.58 %, respectively.

The addition of calcium nitrate depresses the initial swelling of SAP. This is beneficial as it allows a higher SAP dosage, increases the Swelling contrast and decreases the size of SAP voids in cement paste, reducing its impact on strength. At present, the relatively high dosage of bacillus subtilis & sodium polyacrylate used in this study will limit practical applications due to the high costs involved and the undesirable effect on strength. For example, adding 5–15% sodium polyacrylate by weight of cement was found to reduce compressive strength by 55–70%. And the addition of 5–15% Bacillus subtilis by weight of cement was found to reduce compressive strength by 60–85%.

Further work is necessary to establish the feasibility of crack repairing at lower SAP & bacteria dosages and to develop means to limit strength loss. In a simple word from this study addition of 5% or <5% use of material gives the best result in both bacteria and SAP.

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