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Use of Bio-Cement and Nano-Carbon Fibre for the Repair and Rehabilitation of Concrete Cubes

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Abstract: Natural processes, such as weathering faults, land subsidence, earthquakes and human activities create fractures and fissures in concrete structures and historical stone monuments. These fractures and fissures are detrimental since they can reduce the service life of the structure. In the case of monuments and buildings of historical importance, these cracks tend to disfigure and destroy the structure. Therefore it is necessary to remove the cracks of the buildings. Normally artificial materials are used to plug the cracks. Therefore a novel technique for remodelling damaged structural formations has been developed by employing a selective microbial plugging process, in which microbial metabolic activities promote calcium carbonate precipitation. The objective of this work is to quantify the effect of bacterial remediation of concrete using bio-cement application, along with nano-carbon fibres. Bio caulk (Bio+Caulk = Biological material + paste used as sealant) is a biological material which is used as sealant to repair cracks. For the purpose of comparison, techniques using cement mortar and epoxy resin coating are also included. Varying percentages of Nano-carbon along with bio-cement is used and also nano-carbon fibre along with cement mortar is used for remediation. Bio-cement used is prepared using two Medias, nutrient media and brain-heart infusion media. Concrete cubes of size 100mm cast with M20 grade concrete are used and tested after 28 days. The effectiveness of the different types of remediation techniques is obtained in comparison with similar specimen cured in plain water The results are compared and it is concluded that the bacterial immersion and bio caulk application are highly effective when compared to the other techniques. There is about 50 to 60% improvement by using bacterial immersion and bacterial immersion with nano-carbon fibres which is among the highest of all the other test results.
Keywords:- Bio-Cement, Nano-Carbon Fibre...

I. INTRODUCTION

Natural processes, such as weathering faults, land subsidence, earthquakes and human activities create fractures and fissures in concrete structures and historical stone monuments. These fractures and fissures are detrimental since they can reduce the service life of the structure. In the case of monuments and buildings of historical importance, these cracks tend to disfigure and destroy the structure. Therefore it is necessary to remove the cracks of the buildings. Normally artificial materials are used to plug the cracks. Therefore a novel technique for remodelling damaged structural formations has been developed by employing a selective microbial plugging process, in which microbial metabolic activities promote calcium carbonate precipitation.

II. REVIEW OF LITRATURE

A. Calcite Precipitation induced by Polyurethane – immobilized Bacillus pasteurii:

1) *Sookie S. Bang, Johnna K. Galinat, V. Ramakrishnan. Volume 28-(2001) pp404-409[1]:* Polyurethane (PU) foam was used to immobilize the whole cell of Bacillus pasteurii. The immobilized cells exhibited the rates of calcite precipitate in and ammonia production as high as those of the free cells. Scanning electron micrographs identified the cells embedded in calcite crystals through PU matrices. Calcite in PU showed little effect on the elastic modulus and tensile strength of the polymer, but increased the compressive strengths of concretes cubes, whose cracks were remediated with PU-immobilized cells. These observations led us to believe that the calcite might remain as a form of precipitation, not as bonding material within the matrices.

B. The Present and Future of Bio sealant in Crack Remediation

1) Sookie S. Bang 2004(pp -991-1001) [2] : microbiologically induced calcium carbonate ($CaCo_3$) has been introduced in crack remediation as sealant. As a metabolic by product of Bacillus pasteurii, environmentally innocuous inorganic $CaCo_3$ precipitates outside the cell and can persist in the environment for an extended period of time. Once applied, this type of bio sealant is expected to be self-remediating as long as substrates for bacterial growth and mineral ions for $CaCo_3$ precipitation are available. This paper

(1) reviews the principle concepts of microbial $CaCo_3$ precipitation, (2) evaluates the performance of the bio sealant in crack remediation, and (3) provides discussion on the future of bio sealant development that is based on cutting-edge biotechnology.

C. Processing, Structure, and properties of carbon nano fiber filled PBZT composite fiber

1) *Tetsuya Uchida, Thuy Dang, B.G. Min, Xiefei Zhang, Satish Kumar Volume 36(2005) pp 183-187[3]:* The Poly (ρ-phenylene benzobisthiazole) (PBZT)/carbon nano fiber (CNF) c omposite was prepared by in situ polymerization in polyphsphoric acid (PPA), and fibres spun by dry-jet wet spinning. The liquid crystalline PBXT/CNF dope in PPA exhibited excellent spinnability. The PBZT/CNF weight ratio was 90/10. The transmission electron microscope images show isolated and well oriented CNFs with no aggregation. CNF graphite layer stacking in the composite fiber have been observed using high resolution transmission electron microscopy, and showed that graphitic structure of CNFs was not damaged during polymerization in PPA and subsequent fiber spinning and drawing. High resolution transmission electron microscopy also shows that there is no deboning between CNF and the PBZT matrix. Tensile and compressive properties of the composite fibres have been determinate and discussed.

D. Use microorganism to Improve the Strength of Cement Mortar

1) *P. Ghosh, S.Mandal, B.D.Chattapadhyay, S. Pal. – Volume 35(2005) pp1980-1983[4]:* This study describes a method of strength improvement of cement-sand mortar by the microbiologically induced mineral precipitation. A thermophilic anaerobic is incorporated at different cell concentration with the mixing water. The study showed that a 25% increase in 28day compressive strength of cement mortar was achieved with the addition of about 10^5 cell/ml of mixing water. The strength improvement is due to growth of filler material within the pores of the cement-sand matrix as shown by the scanning electron microscopy. The modification in pore size distribution and total pore volume of cement-sand mortar due to such growth is also noted. E. coil microorganisms were also in the cement mortar for comparison, but no improvement in strength was observed.

E. Bacterial Carbonate Precipitation as an Alternative surface Treatment for Concrete

1) *Willem De Muynck, Kathelijin Cox, Nele De Belie and Willy, Verstraete [5]* : Surface treatments play an important role in the in the protection of construction materials from the ingress of water and other deleterious substances. Due to the negative side-effects of some of the conventional techniques, <bacterial> induced carbonate mineralization has been proposed as novel and environmental friendly strategy for the protection of stone and mortar. This paper reports the effects of <bacterial> $CaCo_3$ precipitation on parameters affecting the durability of <concrete> and mortar. i <Bacterial>deposition of layer of calcite on the surface of the specimens resulted in decrease of capillary water uptake and permeability towards gas. This <bacterial> treatment resulted in limited change of the chromatic aspect of mortar and <concrete> surfaces. The type of <bacterial> culture and medium composition had a profound impact on $CaCo_3$ crystal morphology. The use of pure cultures resulted in a more pronounced decrease in uptake of water, respectively less pronounced change in the chromatic aspect compared to the use of mixed ureolytic cultures as paste. The results obtained with cultures of the species Bacillus sphaericus were comparable to the ones obtained with conventional water repellents.

F. Improvement of Concrete Durability with the aid of Bacteria

1) *De Muynck, w., De Belie, N.& Verstraete, w. [6] :* Shortcomings of conventional surface coatings have drawn the attention to alternative treatments for the improvement of the durability of concrete. Promising results of an innovative biotechnology based on microbial carbonate precipitation have lead to research concerning the use of bacteria in or concrete. In our research groups, first the criteria for the selection of calcium precipitating Bacillus strains were established. Bacillus sphaericus strains capable of the remediation of eviller limestone, by precipitating dense and coherent calcium by a high urease activity, abundant EPS-production, a good bio film and a very negative potential.

This paper reports the effects of bacterial $CaCo_3$ precipitation on parameters affecting the transport processes and durability of concrete and mortar. Pure cultures of ureolytic bacteria were compared for their effectiveness and durability on the presence and type of calcium source (Calcium chloride or calcium acetate.) Treatments were evaluated according their influence on transport processes such as water vapour permeability and water and chloride ingress. Microbial calcite precipitation was quantified by X-ray diffraction (XRD) analysis and visuali8zed by SEM. The results indicated the presence of newly formed layer on the surface of the mortar specimens, consisting mainly of calcite. Bacterial deposition of a layer of calcite on the surface of the specimens resulted in a decrease of capillary water uptake and permeability towards gas. This bacterial treatment resulted in a limited change of the chromatic aspect of mortar and concrete surfaces.

G. Microbiologically-Enhanced Crack Remediation (MECR) Sookie S. Bang and V. Ramakrishnan [7]

A novel approach of microbiologically-enhanced crack remediation (MECR) has been initiated and evaluated in this report. Under the laboratory conditions, Bacillus Pasteurii was used to induce $CaCo_3$ precipitation as the microbial urease hydrolyzes urea to produce ammonia and carbon dioxide. The ammonia released in surroundings subsequently increases pH, leading to accumulation of insoluble $CaCo_3$ Scanning electron micrograph (SEM) and x-ray diffraction (XRD) analyses evidenced the direct involvement of microorganisms in $CaCo_3$ prepetition. In biochemical studies, the primary roles of microorganisms and microbial urease were defined. Furthermore, the role of urease in $CaCo_3$ precipitation was characterized utilizing recombinant in polyurethane (PU) polymer were applied to remediate concrete cracks Although microbiologically-induced calcite precipitation enhanced neither the tensile strength nor the modulus of elasticity of the PU polymer, cement mortar whose crack was remediated with the cell-laden polymer showed a significant increase in compressive strength. Thorough detailed investigation, MECR showed an excellent potential in cementing cracks in granitic, concrete, and beyond.

H. Bacteria Carbonate Precipitation Improves the Durability of Cementations Materials, Willem de Muynck, Dieter Debrouwer, Nele de Belie, willy Verstraete .Volume 38(2008) pp 1005 – 1014 [8]

Shortcoming of conventional surface treatments has drawn the attention to alternative techniques for the improvements of the durability of concrete. This paper reports the effects of bacteria carbonate precipitation (bio deposition) on the durability of mortar specimens with different porosity. Durability was assessed from the permeation properties and resistance towards degradation processes The surface deposition of calcium carbonate crystals decreased the water absorption with 65 to 90% depending on the porosity of the specimens. As a consequence rate and chloride migration decreased by about 25-30% and 10-40% respectively. An increased resistance towards freezing nab thawing was also noticed. The results obtained with conventional surface treatments.

I. Microbial Activity on the Microstructure of Bacteria Modified Mortar:

1) *S. Ghosh, M. Biswas, B. D.Chattopadhyay, S. Mandal – Volume 31(2009) pp 93-98[9*]: Micro bial modified or concrete has become an important area of research for high-performance construction material. This study investigates the effects of incorporating a facultative anaerobic hot spring bacterium on the microstructure of a cement-sand mortar. Environmental scanning electron microscopic (ESEM) views and image analysis (IA) of the bacteria modified mortar (thin-section) showed significant textural difference with respects to the control (without bacteria) samples. X-ray diffraction (XRD) study confirmed the formation of new phases of silicates (Gelignite) within the matrix of such mortar material, which causes an improvement in the strength of the material. Electron probe micro-structure analysis (EPMA) suggested that the bacteria treatment promoted uniform distribution of silicate phases and increased the calcium/silicon ration within CSH gel of the matrices. The bacteria is found to leach a novel protein, into mortar also improves the strength of mortar.

J. Bacteria Remediation of Concrete using Bio caulk

1) *V. R. Prasanth Kumar (2009) [13]:* Microbial included crack remediation technique is a method that has been proved beyond doubt of its efficacy. The review of literature carried out in this area indicates that the work related to quantification of the efficiency of repair technique in comparison with conversional methods of repair is scarce. In this work an attempt is made to evaluate the effectiveness of four different remediation techniques that include cement Mortar application, Epoxy Resin, Immersion in Bacterial Solution and use of Bio+Caulk which is a putty like substance with bacterial organisms. The investigation includes two different types of specimens namely cubes and damaged RC Beams subjected to high temperature, that are already available. For the cube specimens two difference water cement ratios (0.44 and 0.56) with normal, porous (no compaction) and cracked cubes are included. The cracking of cubes is done in a pre determine way by inserting a 0.5mm thick aluminium plate to a depth to a depth of 75mm top on a 100mm size of concrete cube of M20 grade mix B.Sphaericus is used for investigation. The investigation of damaged beams includes three different degress of damages namely, Low, Medium and High, determine by Rebound hammer and Ultrasonic Pulse Velocity test. The comparison of results of cubes and rehabilitated beams lead to the conclusion, that the bio caulk application is the most effective one and the cement mortar is the least effective method.

III. OBJECTIVE OF WORK

To evaluate the efficiency of Bio-cement with Nano-carbon fibres in repair and rehabilitation.

IV. SCOPE OF WORK

To use concrete with water-cement ratio of 0.56 and include specimens with 100mm side cubes to compare strengths of uncracked cubes, cracked cubes, cracked cubes with bio-cement and cracked cubes with Bio-cement and Nano-carbon fibres. The crack is made using aluminium plate. The thickness and depth of the crack is 0.9mm and 75mm respectively. Production of Bio-cement from *Bacillus pasteurii* which along with fly ash produces $CaCO_3$.

A. Mechanism

Urease-producing soil bacteria catalyze hydrolysis of urea to produce two molecules of ammonia and one molecule of carbon dioxide. The enzymatic hydrolysis of urea is generally described as:

Urease

$H_2N\text{-}CO\text{-}NH_2 + H2O \longrightarrow 2NH_3 + CO_2$

The ammonia that is released by urea hydrolysis results in an increase in pH of the surrounding medium wherein supplemented mineral ions (Ca^{2+} and CO_3^{2-}) may precipitate out as $CaCO_3$. This process of precipitation is a complex mechanism and is a function of the cell concentration, ionic strength and pH of medium. Thus, the media for the growth of the microorganism are supplemented with a calcium source, such as calcium chloride, which is precipitated as calcium carbonate by the following complex set of reactions: **(Deepak *et al.*, 2008)[11]**

$Ca^{2+} + Cell \longrightarrow Cell\text{-}Ca^{2+}$

$Cl^- + HCO_3^- + NH_3 \longrightarrow NH_4Cl + CO_3^{2-}$

$Cell^-Ca^{2+} + CO_3^{\ 2-} \longrightarrow Cell\text{-}CaCO_3$

V. TESTING OF PREPARED CUBES

The cubes (100mm3) were cast using the formulated design mix and tested at 7, 14 and 27 days and the results are tabulated below.

Table 3.1 Preliminary Test Results

Sl.No.	Days Of Curing	Weight (Kg)	Compressive Strength(N/mm2)
1	7	2.50	10
2	14	2.52	15
3	27	2.52	19

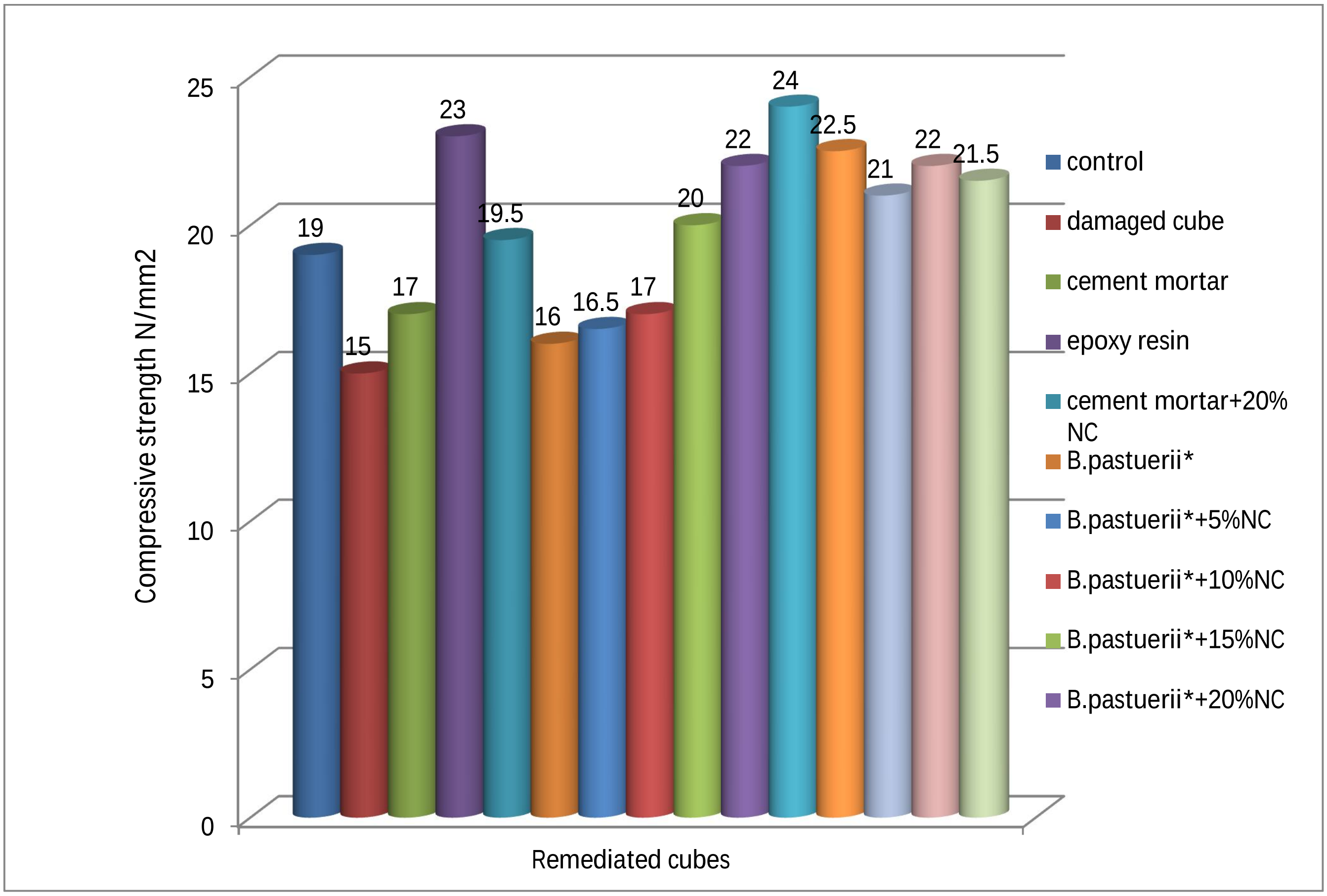
VI. RESULTS

The compressive strength of the variably remediated concrete cubes is presented in the table below.

Table 4.1 Test Results of the Remediated Cubes

Sl.No.	Detail	Compressive Strength(N/mm^2)
1	Control	19
2	Damaged Cube	15
3	Remediated with Cement mortar	17
4	Remediated with Cement mortar + 20% Nano-Carbon Fibre	19.5
5	Remediated with Epoxy Resin	23
6	Remediated with B.pastuerii*	16
7	Remediated with B.pastuerii* + 5% Nano-Carbon Fibre	16.50
8	Remediated with B.pastuerii* + 10% Nano-Carbon Fibre	17
9	Remediated with B.pastuerii* + 15% Nano-Carbon Fibre	20
10	Remediated with B.pastuerii* + 20% Nano-Carbon Fibre	22
11	Remediated with B.pastuerii**	24
12	Remediated with B.pastuerii** + 5% Nano-Carbon Fibre	22.5
13	Remediated with B.pastuerii** + 10% Nano-Carbon Fibre	21
14	Remediated with B.pastuerii** + 15% Nano-Carbon Fibre	22
15	Remediated with B.pastuerii** + 20% Nano-Carbon Fibre	21.5

*B.pastuerii Cultured in nutrient media
**B.pastuerii cultured in brain-heart infusion



Comparison of Compressive Strength of Remediated Cubes by Various Methods

VII. CONCLUSION

The bio-cement can be produced using bio-column and used for remediational works.
The crack in the concrete cube reduces its compressive strength by 21.05%.
The maximum increase in strength is found when remediated by the following methods The bacterial (B.pasteurii) ** treatment of this intentional crack has increased to about 60% of strength compared to the cracked cubes.
The epoxy resin treatment of this intentional crack has increased to about 53.55%.
The bacterial (B.pasteurii) ** +5% treatment of this intentional crack has increased to about 50% of strength compared to the cracked cubes A proportional increase is found in the compressive strengths of concrete cubes on addition of nano-carbon fibres in increasing quantities (0g, 2g, 4g, and 8g) in the mix.

VIII. SCOPE FOR FUTURE STUDY

Tensile strength of concrete cubes with nano-carbon fibre can be carried out. Field studies can be taken up

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