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MICROBIAL PROTEIN — AN INNOVATIVE ADDITIVE FOR CEMENTITIOUS MATERIALS

Brajadulal Chattopadhyay[b], Saroj Mandal[a*] Henk M Jonkers[c] Ye Guang[c] Sudipta Majumdar[b], and Trinath Chowdhury[b]

[a]Department of Civil Engineering, Jadavpur University, Kolkata – 700032, India,
[b]Department of Physics, Jadavpur University, Kolkata – 700032, India,
[c]Department of Civil Engineering & Geosciences – Microlab, Delft University of Technology, The Netherlands

A B S T R A C T

Addition of microbial protein extracted from microorganisms of a typical hot spring increases the compressive strength of cement paste and mortar samples. The microstructure of such protein amended samples indicates more hydration of cement particles in the matrices resulting in increment of calcium and silicate percentages within calcium-silicate-hydrate gel. Modification of pore size distributions in the protein incorporated cement matrices was also established. Nano-indentation study showed improvements in hardness and dynamic elastic modulus of protein treated mortar samples. Such protein addition in cement matrices may be useful for the development of high performance concrete and also as a suitable repair material in near future.

K e y w o r d s

Microstructure, Microbial protein, pore size distribution, Dynamic modulus of elasticity

1.0 INTRODUCTION

Various additives or chemical admixtures are usually added in concrete in order to improve the various properties of the concrete products and also to repair cracks and fissures in concrete structures. But not all these are easy and good to use, and moreover, may sometimes cause environmental pollution [1], [2], [3] and [4]. The major cause that initiates various mechanisms of concrete deterioration is the process of cracking what dramatically increases the permeability of concrete and ultimately reduces its durability. Therefore, care should be taken to minimize the effect for crack formation or to repair the cracks, preferably by incorporation of a compatible potential additive which will ultimately reduce the matrix permeability.

In the biosphere, some special microorganisms can function as geochemical agents, promoting the dispersion, fraction and /or concentration of matter [6]. The microbial processes resulting in the concentration of matter and the formation of minerals inside the cement-based matrices constitute an area of research of growing interest [7]. It has been observed that a specific microorganism isolated from a hot spring of Bakreshwar, West Bengal, India when incorporated to mortar or concrete mixtures could increase both the compressive and tensile strengths of the specimens [8] and [9]. This specific facultative-anaerobic and iron reducing bacterium, when added directly at different cells concentrations to the mortar mixture also improves the durability and overall quality of the resulting mortar [12], [13] and [14]. Other studies have shown that the different beneficial microorganisms can actively deposit inorganic substances such as calcite, gehlenite etc inside the matrices that can be used as a filling material to remediate cracks within the structures [10], [11] and [12]. All these phenomena are mainly guided by some biochemical process associated with some proteins (enzymes) within bacteria that direct either the prevention or the creation of mineral deposits and hence play the active role in such modification [15].

It has been noted that in all the previous research the microorganisms are added to the mixing water along with suitable nutrient during the preparation of concrete/ mortar. However, the present study shows that a specific protein extracted from the bacterium strain BKH1 (Gene bank accession number FJ177512) [16] plays a key role on modification of the properties cement paste. The study includes the determination of compressive strength, microstructure analyses by Environmental Scanning Electron Microscope (ESEM) and Energy Dispersive X-ray analyzer (EDX), matrix porosity study by Mercury Intrusion Porosimeter (MIP) and matrix property study by nano indentation tests of the protein incorporated cementitious materials.

2.0 EXPERIMENTAL PROGRAM

All the required chemicals were supplied by Sigma Chemical Co, USA; MERCK, Germany and Spectrochem Pvt. India Ltd, India. CEMI 42.5 N cement (ENCI, the Netherlands) and natural sand (particles sizes of 125–250, 250–500 and 500–1000 μm diameters with a ratio of 1 : 1 : 1 respectively) of Netherlands were used in this study.

2.1 Bacterial Protein

An innovative bacterial strain 'BKH1' (Gene Bank

* Corresponding author
Tel : +91 33 24169490
E-mail : mailtosarojmandal@rediffmail.com

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EFFICIENT FINITE ELEMENT MODEL OF REINFORCED CONCRETE BEAM STRENGTHENED WITH FIBRE REINFORCED POLYMER SHEET

Kaushal B. Parikh[a*], C. D. Modhera[b]

[a*]Department of Applied Mechanics, Government Engineering College, Surat – 395001, Gujarat, India
[b] Department of Applied Mechanics, Sardar Vallabhbhai National Institute of Technology, Surat – 395007, Gujarat, India

A B S T R A C T

Numerical analyses are performed using the ATENA finite element program (nonlinear analysis software) to predict accurately the ultimate load carrying capacity of reinforced concrete beams strengthened by fibre reinforced polymer sheet applied at bottom. Constitutive models are used to simulate the nonlinear behaviour of plain concrete, steel reinforcement and fibre reinforced polymer sheet. The influences of beam length, fibre reinforced polymer sheet length, layers of sheet and distance between loading points on the ultimate strength of beam are investigated. This FE modelling is used to predict the load-carrying capacity and the applied load-midspan deflection response of RC (Reinforced Concrete) beams. The proposed 3D finite element model is also able to predict the type of failure of beam. Finite element simulation and experiment measurement are compared based on numerous tests available on the literature and published by different authors. The finite element simulated response agrees remarkably well with the corresponding experimental results. Thus this accurate and efficient finite element modelling of flexural strengthening of RC beam with externally bonded FRP (Fibre Reinforced Polymer) sheets/plates is suitable for practical use in design-oriented parametric studies.

K e y w o r d s

Reinforced concrete, Fibre reinforced polymer sheet, Strengthened beam, Finite element modelling.

1.0 INTRODUCTION

Fiber reinforced polymer laminates are increasingly being applied for the rehabilitation and strengthening of infrastructure in lieu of traditional repair techniques such as steel plates bonding. FRP plates have many advantages over steel plates like high corrosion resistance, ease of handling and their use can be extended to situations where it would be impossible or impractical to use steel [1-3]. Also, since FRP plates used for external bonding are relatively thin, neither the weight of the structure nor its dimensions are significantly increased. The study of using FRP to strengthen reinforced concrete structures just started in the 1990s [4-5], the technology is currently widely used.

To study the behaviour of reinforced concrete structures strengthened by FRP, the fundamental step is to understand the nonlinear behaviour of the constitutive materials, reinforced concrete and FRP separately. The nonlinear behaviour of reinforced concrete such as concrete cracking, tension stiffening, shear retention, concrete plasticity and yielding of reinforcing steel have been extensively studied by various researches and numerous proper constitutive laws have been proposed [6, 7]. However, in the literature, most studies of reinforced concrete structures strengthened by FRP have assumed that the behaviour of FRP is linear. In this presented study also stress-strain relationship of FRP is assumed linear.

* Corresponding author
Tel : +91 – 9228749042
E-mail : kbp1977@yahoo.co.in

In this investigation, proper constitutive models are introduced to simulate the nonlinear behaviour of reinforced concrete and FRP. Then the finite element program ATENA [8] is used to perform a failure analysis of rectangular reinforced concrete beams strengthened by FRP. In this paper the finite element modelling of strengthened beam with FRP will be discussed and the presented model is used for verification of numbers of experimental tests, obtaining finally an average absolute error less than 15%.

2.0 FINITE ELEMENT MODELLING

2.1 Material Properties and Constitutive Models

The materials used in the analysis involve concrete, steel reinforcing bars and FRP. Reliable constitutive models applicable to steel reinforcing bars and concrete are available in ATENA material library. Linear stress-strain relation is assumed for FRP, this present study.

2.1.1 Concrete

The uniaxial compressive strength f'_t is selected first. Under uniaxial compression the concrete strain ε_c corresponding to the peak stress is usually around the range of 0.002–0.003. A representative value $\varepsilon_c = 0.0035$ [9], is used in the analysis.

The Poisson's ratio ν_c of concrete under uniaxial compressive stress ranges from 0.15–0.22., with a representative value of 0.19 or 0.20 [11]. In this study, the Poisson's ratio of concrete is assumed to be $\nu_c = 0.20$. The uniaxial tensile strength f'_t is difficult to measure and

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SELF-COMPACTING CONCRETE AS A REPAIR MATERIAL — SOME GENERIC ISSUES

Subrato Chowdhury[a*], Sandeep D. Kadam[a]

[a]UltraTech Cement Ltd, Mumbai – 400 093, India

ABSTRACT

Self–compacting concrete (SCC) is emerging as a potential repair material because of its significantly improved performance compared to traditional concrete (TC). However, for SCC to be an effective repair material one has to consider several pre-requisites, which include proper characterization procedure for ingredients, effect of ingredients characteristics on the determination of mix composition to meet target performance of rheology and strength, criteria to determine ingredient quantities satisfying the target performance, and robustness of the mix. An experimental exercise is undertaken to study the issues related to mix proportioning of SCC with supplementary cementitious material such as fly ash and outcome of the exercise suggests that rheological characterization of ingredients is necessary in addition to the conventional approach based on physical and chemical characteristics. A rational method to proportion optimum SCC mix should be based on explicit criteria to meet target performance taking directly into account the ingredient characteristics. Higher powder content and the composition of powder are favourable for the robustness of the mix.

Keywords

Self–compacting concrete (SCC), Mix proportioning, Rheology, Ingredient characterization, Robust mix.

1.0 INTRODUCTION

Self Compacting Concrete (SCC) is characterized in its fresh state by high flowability as well as rheological stability [1]. The potential of SCC applicability is excellent for the repair and rehabilitation of elements with complicated geometry and thin sections. There are numerous economic, environmental and engineering/architectural benefits of using SCC in repair. Lack of uniformity and complete compaction in repair and rehabilitation of thin concrete sections may cause durability problems.

SCC can be viewed as a class of High Performance Concrete (HPC) with special attributes of self–compaction during placement [1, 2, 3, 4, and 5]. This attribute of SCC makes it a potential material for traditional concrete repairs. SCC as a repair material is successfully used in many structures in different parts of the world. Baltimore-based Structural Preservation Systems (SPS) began incorporating SCC into a variety of projects after getting positive results from the mock-up. One such project was the strengthening of deficient cast-in-place post-tensioned reinforced beam in Washington, DC parking garage via external post-tensioning that was subsequently encased in SCC [6].

SCC has also been used successfully in the repair of the lining of the Les Monts tunnel located on the urban expressway which bypasses the town of Chambery in the French Alps. The SCC here had to satisfy stringent performance requirement of retention of fresh behaviour for 2 h, compressive strength of 10 MPa at 16 h and 45MPa at 28 days and good resistance against frost & alkali-aggregate-reaction. All the above requirements were successfully met. The maximum size of aggregate (MSA) used was 10mm rounded gravel [7].

Transport Quebec had successfully developed and used SCC for repair of the soffit of the Champlain Bridge Deck & rehabilitation of the Notre-Dame-de-Grace Tunnel on Autoroute 15 in Montreal. Rapid setting SCC (RS-SCC) was used with 10 mm MSA aggregates. RS-SCC developed sufficient compressive strength to allow reopening of traffic within 3 hours. RS-SCC has been successfully used in other repair applications such as bearing pad supports, repairs to AASHTO beams, pre-stressed concrete structures, machinery bases as well as emergency repairs [8]. The repair layer compactness has significant effect on bonding strength since the more the repair layer penetrates into the voids the more mechanical interlock between two layer is obtained [9].

Given its very special viscoplastic properties, the use of SCC represents a major advantage since it limits the formation of cracks. During the repair project of Jarry/Querbes underpass in Montreal 420 m^3 of fiber-reinforced SCC was used to repair a 1700 m^2 surface (retaining walls, abutments and columns), making this the first major repair project in Quebec using fiber-reinforced SCC [10].

2.0 SPECIAL PROPERTIES OF SCC MIXES

For mouldability, a fresh SCC mix should have appropriate workability to fill all the space within the formwork (filling ability), passing through the obstructions caused by reinforcement and/or embedment (passing ability) and maintaining its homogeneity (resistance to

* Corresponding author
Tel : +91 – 22 – 66928400
E-mail : subrato.chowdhury@adityabirla.com

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BEHAVIOUR OF REINFORCED CONCRET BEAM-COLUMN JOINT RETROFITTED WITH CARBON-FIBRE-REINFORCED POLYMER WRAP

K. Balasubramanian[a*], N. Lakshmanan[a], C. Antony Jeyasehar[b], T. S. Krishnamoorthy[a] and B. H. Bharatkumar[a]

[a]CSIR-SERC, Taramani, Chennai – 600 113, India.

[b]Annamalai University, Annamalainagar – 608 002, India.

A B S T R A C T

FRP materials have a number of favourable characteristics, including: ease of installation; immunity to corrosion; extremely high strength; availability in convenient "to apply" forms etc. In recent years, the technique of strengthening RC columns using FRP composites has been used increasingly to replace steel jacketing. Beam-column joints, being the key lateral and vertical load resisting members in RC structures are particularly vulnerable to failures in earthquakes and hence their retrofit is often the key to successful seismic retrofit strategy. Investigations were taken up at Structural Engineering Research Centre (SERC), Chennai, India to study the behaviour of RC beam-column joints retrofitted with Carbon-Fibre-Reinforced Polymer (CFRP) wraps. A corner bar has been introduced at the beam column joint location to improve the joint efficiency. It is concluded that, in situations, where deficiencies are encountered in both design of main reinforcement and spacing of stirrups, retrofitting of such structural members with a CFRP will restore the load capacity of the member. Results of the investigations are presented in this paper.

K e y w o r d s

Reinforced concrete column-beam joint retrofit, Strengthening, Carbon-fibre-reinforced polymer wraps

1.0 INTRODUCTION

Last decade earthquakes worldwide have illustrated the vulnerability of existing reinforced concrete (RC) beam-column joints to seismic loading. Beam-column joints, being the key lateral and vertical load resisting members in RC structures are particularly vulnerable to failures in earthquakes and hence their retrofit is often the key to successful seismic retrofit strategy. Upgradation to higher seismic zones of several cities and towns in the country has also necessitated in evolving new retrofitting strategies [1-6].

Until the early 1990s, constructing an additional reinforcement cage with concrete jacketing and installing grout-injected steel jackets were the two common methods for strengthening deficient RC beam column joints. Steel jacketing is more effective than caging, because the later results in substantial increase in the cross sectional area and self-weight of the structure. Both methods are however labour intensive and sometimes difficult to implement at the site. In addition to being heavy, steel jackets are poor in resisting weather attacks. In recent years, the technique of strengthening RC columns using FRP composites has been used increasingly to replace steel jacketing. The initial developments of the FRP strengthening technique took place in Germany and Switzerland. Strengthening of reinforced concrete members with externally wrapped FRP laminates has been studied in detail by researchers at several institutions [7-15]. The results obtained proved the FRP strengthening technique is highly efficient and effective, especially when the FRP materials are made using carbon fibers and have led to hundreds of application worldwide.

* Corresponding author
Tel : +91 9445003992 / 9940388556
E-mail : baluserc@yahoo.com

FRP materials have a number of favourable characteristics, including: ease of installation; immunity to corrosion; extremely high strength; availability in convenient "to apply" forms etc. Various investigators have conducted comprehensive research programs that were aimed at expanding the range of applicability of the FRP strengthening techniques to poorly detailed critical shear RC joints. The simplest way to strengthen such joints is to attach (through epoxy bonding) FRP sheets or strips to the joint region with the fibers in two orthogonal directions. This concept combines ease of application with enhanced performance of the joint to lateral loads, as the 2D fiber system of the wrap in the joint will also act as shear reinforcement.

Only a very few documented studies are available on the performance of RC beam-column joints strengthened with Carbon Fiber Reinforced Polymer (CFRP) wraps in India. Hence to fulfill this gap, investigations were taken up at Structural Engineering Research Centre (SERC), Chennai to study the behaviour of RC beam-column joints retrofitted with CFRP wraps. A corner bar has been introduced at the beam column joint location to improve the joint efficiency.

CASE STUDY

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REPAIR OF DISTRESSED BRIDGES AND CULVERTS ON A NATIONAL HIGHWAY IN INDIA – A CASE STUDY

Mohan Kumar M.[a*]

[a]Pidilite Industries Limited, Mumbai – 400059

ABSTRACT

The old distressed bridges and culverts between Chikkaballapura to Bagepalli in the State of Karnataka in India on the National Highway No. 7 were repaired and rehabilitated by using polymeric repair materials in the year 2009 - 2010. The repair work consisted of corrosion treatment as well as the repair of spalled and extensively damaged concrete. The structures were strengthened by injection grouting in cracks and honeycombs. The deck slab and piers were additionally protected with anti-carbonation coatings for long term durability. The present case study narrates the step by step approach taken during this repair and rehabilitation project.

Keywords

Rehabilitation, Bridges, Anti-corrosive treatment, Injection grouting, Anti-carbonation coating

1.0 BACKGROUND

A wellknown Indian Construction Company had undertaken the project of upgrading a segment of the National Highway No. 7 to 4/6 lane divided carriageway configuration. This project was a part of the construction of North-South corridor in the State of Karnataka (Andhra/ Karnataka Border to Avathi Village 463.00 km. to 524.00 km.) under National Highway Authority of India (NHAI). The project also included construction of some new bridges and repair and rehabilitation of old bridges between Chikkaballapura to Bagepalli. Additionally, existing small bridges had to be widened and additional structures had to be provided by the side of these old bridges. The clients were also concerned about the economic implications of the total project. These bridges had to be strengthened as per the required loading standards of National Highway Authority of India. Pidilite Industries Ltd, Mumbai was the prime supplier of repair materials to this project.

2.0 CONDITION SURVEY

A condition survey was carried out by visual inspection after which some bridges and culverts were identified for repair and rehabilitation. The following signs of distresses were observed:

- Spalling of concrete on the end beams (Figure 1)
- Exposed reinforcement and corrosion (Figure 2)
- Spalled concrete on the piers (Figure 3)
- Small to large honeycombs (Figure 4)
- Cracks at different locations (Figure 5)

*Corresponding author
Tel : +91 - 9341983222
E-mail : mohan.kumar@pidilite.com

The deterioration was essentially due to the combined environmental diffusive effects of oxygen, moisture and carbon dioxide.

The various components of the bridges that needed to be strengthened were deck slab area, deck slab and pier together, deck slab and side piers, either side of the pier, construction joints, beams, slabs and pier.

Figure 1. Spalled concrete at the edges

Figure 2. Spalled concrete and reinforcement corrosion