INTERNATIONAL
Journal of 3R' s

Vol.1, No.3, 2010, 95-101

PERFORMANCE OF FRP STRENGTHENED REINFORCED CONCRETE COLUMNS AT VARIOUS LEVELS OF REINFORCEMENT CORROSION – AN EXPERIMENTAL STUDY

S. Sundar Kumar[a*], G. Ramesh[a], B. H. Bharatkumar[a] and T. S. Krishnamoorthy[a]

[a]CSIR - Structural Engineering Research Centre (Council of Scientific and Industrial Research) CSIR Madras Complex, Taramani, Chennai 600113, India

ABSTRACT

Retrofitting and restoration of RC Structures is becoming a major area of interest in structural engineering with the ageing of large number structures around the world. One of the main forms of deterioration in RC Structure is corrosion in the reinforcement. Corrosion being a natural phenomenon is very difficult to be prevented. The porous nature of concrete aided with cracks at service stage forms a perfect medium for external agents which aid in reinforcement corrosion to reach the steel. FRP wrapping is being widely used in restoring the loss in load capacity of the columns. This paper presents the results of the experimental investigation carried on column specimens with corroded reinforcements. The columns were subjected to impressed current to accelerate the corrosion process in the columns. After certain duration of exposure to impress current the columns were strengthened with carbon fibre fabric and tested for axial load carrying capacity. A few columns were subjected to impress current even after strengthening. The result of the tests confirms the efficiency of the carbon fibre not only in restoring the load carrying capacity but also in acting as an effective barrier in preventing further deterioration due to corrosion.

Keywords

Corrosion, Potential measurement, Corrosin, FRP strengthening, Carbon FRP wrapping.

1.0 INTRODUCTION

Reinforcement corrosion has been widely reported in literature over the last two to three decades. One of the major durability problems is the rebar corrosion in concrete, when it is exposed to the chlorides. Carbonation of concrete or penetration of acidic gases into the concrete,are the other causes of reinforcement corrosion. Besides these, there are a few more factors, some related to the concrete quality, such as w/c ratio, cement content, impurities in the concrete ingredients, presence of surface cracks, etc. and others related to the external environment, such as moisture, oxygen, humidity, temperature, bacterial attack, stray currents, etc., which affect reinforcement corrosion.

Since the rust produced as a result of corrosion has a volume two to four times than that of steel, it causes volume expansion developing tensile stresses in concrete, which ultimately results in cracking and spalling of the cover concrete. Due to the loss of cover concrete, steel may be more accessible to the aggressive agents leading towards further corrosion at an accelerated rate. Corrosion reduces the cross-sections of the steel and thereby the load carrying capacity of the structure. Pitting (i.e., localized) corrosion of the rebar is more dangerous than uniform corrosion, because it progressively reduces the cross-sectional area of rebar to a point where the rebar can no longer withstand the applied load leading to a catastrophic failure of the structure. Besides the loss in the area of the steel, the changes that occur in its properties such as it ductility, young's modulus are also not favorable. The assessment of the causes and extent of corrosion is carried out using various electrochemical techniques.

Depending upon the specific condition of deteriorated structure, the option of the repair methods are steel jacketing, concrete jacketing, FRP wrapping, etc. However, the conventional repair method consists of removing the damaged concrete cover and providing a concrete jacket, has several limitations. Removing the corrosion damaged concrete in the cover region causes load redistribution and the exposed steel reinforcement may buckle and loose its capacity. Thus, there is a need for support system and normal activity comes to a halt during the repair process. Consequently, engineers are looking for an innovative and cost-effective repair solution. In recent years, the technique of strengthening columns using Fiber Reinforced Polymer (FRP) Composites has been used increasingly to replace steel and concrete jacketing. Retrofitting RC columns with FRP material is a novel, but well established technique based on their high strength to weight ratio. FRP external shells prevent or mitigate environmental degradation of the concrete and consequent corrosion of steel reinforcement. The common form of FRP column strengthening involves the external wrapping of FRP sheets.

Fiber Reinforced Plastic composite materials have been used for years as a method of providing added strength and ductility to reinforced concrete structures. The conventional FRP system is a fabric saturated with an

*Corresponding author
E-mail : ssk.serc@gmail.com, ssk@sercm.org

INTERNATIONAL
Journal *of* 3R' s

Vol.1, No.3 , 2010, 102-111

PERFORMANCE EVALUATION OF ENGINEERED CEMENTITIOUS COMPOSITE AS A MATERIAL FOR REPAIR AND RETROFIT

Subhash C. Patodi[a*], Jashvant D. Rathod[b]

[a*]Parul Institute of Engg. & Tech., Limda, Vadodara, Gujarat, India
[b] M. S. University of Baroda, Vadodara, Gujarat, India

ABSTRACT

Total replacement of deteriorated or under designed concrete structures is economically not feasible. The solution lies in repair and retrofit of such structures. The success or failure of repair and retrofit technology often depends on the choice of material. This paper attempts to lay out property requirements of a repair material in which the material ductility and not just the strength translates into strong and ductile structural performance. A smart material which is known as Engineered Cementitious Composite (ECC) has been designed with extreme ductility of several hundred times that of current repair materials. The lower modulus of elasticity and the unique high delamination and spall resistance make ECC an ideal material for the repair of concrete structures. In the present paper ECC, developed by the authors using polyester type of fibers, is demonstrated to satisfy most of the requirements of a durable repair material.

Keywords

Engineered Cementitious Composite, Delamination, Splitting, Durability, Compatibility.

1.0 INTRODUCTION

It has been observed that up to half of the repair works of the concrete structures do not give satisfactory performance. About three-fourths of the failure can be attributed to the lack of durability while the remaining can be attributed to the structural failures. This inadequate performance is often ascribed to inappropriate material selection, improper repair methodology or a combination of both. Failure of concrete repair typically manifests due to cracking in the repair material and/or delamination from the substrate concrete which is largely a consequence of non-uniform volume change under restrained conditions. Despite a large number of investigations and plenty of repair materials, durable concrete repair remains a challenge to the repair industry and researchers [1].

It is well known that a proper bond between the repair and substrate materials is very important. Failure can initiate from an interfacial defect causing delamination in the case of a weak bond and spalling in the case of an overlay strong bond and a brittle repair material. If failure of the repaired system (delamination or spalling) is governed by a fracture process, characterization of the interface by bond strength becomes questionable. As the laboratory specimen size, geometry, loading configuration and flaw size are quite different from those in the field, the bond strength calculated in the lab sometimes does not produce predictable results under field conditions. Also, as elimination of delamination naturally gives preference to spalling and vice versa, it becomes a dilemma that both material failure types can not be just eliminated simultaneously [2].

* Corresponding author

Tel: +91 9998070612
E-mail: sc.patodi@gmail.com.

One of the main reasons for lack of poor long term structural performance under sustained static loading is the corrosion of the reinforcement which results into cracking (Figure 1) and spalling (Figure 2) of concrete due to poor resistance of concrete in tensile stress as shown in Figure 1. Poor structural performance can not be just improved by increasing the compressive strength of concrete as it leads to increase in brittleness. Corrosion of the reinforcement may get initiated at slower rate even in crack free cover material because of carbonation, presence of chlorides from cement or chemical admixture, presence of some moisture in the form of free water etc. Corrosion process produces bursting force which induces axial tension in the cover concrete in which concrete is very weak resulting into cracking parallel to the reinforcement. Corrosion process may become faster with ingress of water, chemical etc. through these cracks. Also, alkali-aggregate reaction exerts tremendous pressure on outer surface resulting into cracking in the material. Therefore, the most urgent need in concrete repair is to somehow enhance the mechanism of resistance to axial tension.

Figure 1. Effect of corrosion of reinforcement in longitudinal cracking in column.

INTERNATIONAL
Journal of 3R' s

Vol.1, No.3, 2010, 112-121

WHITETOPPING AS A TECHNIQUE FOR REHABILITATION OF ASPHALT PAVEMENTS UNDER HEAVY TRAFFIC

D. R. Jundhare[a*], K. C. Khare[a] and R. K. Jain[b]

[a]Sinhgad College of Engineering, Vadgaon (Bk.), Pune - 411041. M.S. India

[b]Pad Dr. D.Y. Patil Institute of Engineering and Technology, Pimpri, Pune - 411018 M.S. India

ABSTRACT

Whitetopping is a cement concrete overlay constructed on the top of existing Hot Mixed Asphalt (HMA) pavement. It is a form of pavement rehabilitation that is designed to extend the life to a deteriorated HMA pavement. This paper discusses about methodology adopted for the construction of unbonded conventional whitetopping for a stretch of Mumbai - Pune arterial road within the limits of Pimpri Chinchwad Municipal Corporation, Pune, India as a rehabilitation technique to a deteriorated HMA pavement. Benkelman Beam Deflection (BBD) test has been conducted to evaluate the strength of existing HMA by finding out its modulus of subgrade reaction (k). To optimize the overlay thickness, relationship between modulus of subgrade reaction (k) of HMA and stresses/deflection induced in the pavement has been developed using 2D closed form formulae. It is revealed from this study that construction of whitetopping overlay has many additional advantages as compared to other conventional rehabilitation techniques such as cost effectiveness, time saving and saving of natural resources.

Keywords

Whitetopping overlays, Benkelman Beam, Deflection measurements, Hot Mix Asphalt, Modulus of subgrade reaction, Traffic Volume

1.0 INTRODUCTION

Total length of road network in India is 3.32 million km (Source: Department of Road Transport and Highways, Govt. of India) out of which 98% of roads are paved with hot mix asphalt (HMA). These roads are subjected to rutting and fatigue cracks due to overloading, poor maintenance, improper drainage system and faulty construction techniques. Thus a huge amount of money is required for repair and maintenance of these HMA pavements. Such pavements can be rehabilitated by laying either flexible overlay or whitetopping. However, the average life of flexible overlaid pavement is less than 5 years [1]. Studies on conventional whitetopping proved that it can be an alternative for HMA maintenance and repair due to its better performance and durability. Also the success of design of such whitetopping is attributed to the uniform support and bond provided by the underlying HMA pavement [2]. In the present study methodology adopted for the construction of unbonded conventional whitetopping on an arterial road of Pimpri-Chinchwad city has been presented. Pimpri-Chinchwad city is a twin city of Pune and is one of the fast growing cities of Maharashtra, India. In the transport world city is also recognized as Auto Nagar or the Detroit of India due to the presence of several automobile ancillary units. Mumbai - Pune arterial road is one of the important links between Pimpri-Chinchwad and Pune city. To improve the efficiency of the road network of this city, it was decided to widen and strengthen the existing pavement surface of proposed road. Total length to be strengthened was 9.0 km which has been taken for this study. Total width of proposed road was 61 m. Out of which strengthening and improvement by providing whitetopping has been done on the existing HMA road having 18.0 m width of two lane dual divided corridor to be used as express corridor. Along with express corridor at center there is 21.5m wide HMA service road on either side of main concrete carriageway for two way traffic or other traffic facilities like cycle track, utility services and landscaping..

* Corresponding author
Tel: +91 9922501833
E-mail : djundhare@yahoo.com

2.0 REVIEW OF LITERATURE

Cement concrete overlays have been used to rehabilitate existing concrete pavements since 1913 and to rehabilitate existing asphalt pavements since 1918 [3]. Around the mid-1960s, many highway agencies began to search for alternative means of rehabilitating existing pavements, and the use of concrete overlays increased significantly [2]. In the 1990s, there was an even higher increase in the use of concrete overlays, spurred by improvements in concrete paving technology. For example, the use of zero clearance pavers, fast-track paving concepts, and high-early-strength concrete mixtures greatly increased the ability of concrete overlays to serve as a viable rehabilitation alternative. Parallel with the increased use of concrete overlays, significant research aimed at advancing the state of the knowledge of concrete overlay construction methodology and performance was carried out.

In recent years, whitetopping has evolved as a viable rehabilitation technique for deteriorated asphalt cement concrete (ACC) pavements. Numerous projects have been constructed and tested; these projects allow researchers to identify the important elements

INTERNATIONAL
Journal *of* 3R' s

Vol.1, No.3, 2010, 122-125

PROPERTIES AND APPLICATION OF A SPECIALLY FORMULATED UV-RESISTANT & HEAT REFLECTING ACRYLIC CO-POLYMER MEMBRANE FOR WATERPROOFING OF ROOFS

Dien Pandiman[a*]

[a]Pidilite Innovation Centre Pte. Ltd., 61 Science Park Road, The Galen, # 03-11/12, Singapore Science Park III, Singapore-117525

ABSTRACT

There are various technological alternatives available for the waterproofing of roofs. Parallely diverse products have been developed and used. Of all these alternatives, a specially formulated water-borne acrylic co-polymer resin appears to show multifarious advantages of uv-resistance, heat reflectance, crack-bridging ability, etc. The product is essentially brushable, making the application easy. Since no organic solvents are involved, there are specific environmental benefits. The present paper is an attempt to characterize such a product through relevant standard tests with a view to demonstrating its durable application.

Keywords

Acrylic co-polymer coating, Roof Waterproofing, Elastomer, Breathability, Bond strength.

1.0 INTRODUCTION

Waterproofing technology evolved steadily from "old" hot/cold liquid applied bitumen to "new" water-borne acrylic co-polymer waterproofing membrane. In the process a large variety of waterproofing materials have been developed to choose for different applications. Material selection is one of the keys for achieving an effective durable waterproofing system. The wrong choice of a waterproofing material can be disastrous for a building.

Before selecting the roof waterproofing material one must make sure that it possesses the following properties:

- Weathering and UV Resistance
- High Tensile Strength and Elongation
- Crack Bridging Capabilities
- Chemical and Alkali Resistance
- Good Bonding Strength
- Low Water Absorption, withstanding hydrostatic pressure
- Breathable, permeable to vapour transmission
- Good Colour Retention
- Algae and Fungus Resistance

The present paper is devoted to a specially designed acrylic co-polymer resin based waterproofing membrane that satisfies the above requirements.

* Corresponding author
Tel.: +65 98792112,
E-mail : dien@pidilite.com.sg

2.0 CHOICE OF ACRYLIC POLYMER AS A BASE FOR ITS PROCESSING AS A WATERPROOFING MEMBRANE

Since their introduction decades ago, acrylic polymers have gained a strong foothold in the coating as a result of their improved flexibility and adhesion compared to polyvinyl acetate emulsions, phenolics, and styrene butadiene latex. In addition, their significantly improved outdoor durability, including resistance to ultraviolet degradation, has mandated their use in several applications.

It may also be relevant to mention here that in the selection of organic binders, copolymers combining different acrylic groups are widely used. As each group has its own typical range of performance characteristics, copolymers can often provide properties that are quite different from a single homo-polymer.

Along with the binder selection, the choice of solvent is important. Coatings in which water is the primary vehicle, generally offer significant advantages including low odor and toxicity, compliance of volatile organic compound (VOC), ease of clean-up and reduced fire hazard in storage.

In addition, what is needed in the formulation is the elastomeric property of the coating at different temperatures.

Keeping in view all these requirements and possibilities a synthetic organic acrylic copolymer resin has been formulated as a binder to "glue" pigments, extenders and special fillers together. It was polymerised from an acrylic monomer with other monomer(s) forming long-chain backbones of polymers with high

CASE STUDY

INTERNATIONAL
Journal *of* 3R' s

Vol.1, No.3, 2010, 126-134

RESTORATION OF A CENTURY-OLD HERITAGE BUNGALOW IN INDIA

Ravi Gundu Rao[a*]

[a]Ravi Gundu Rao and Associates, 1070, 1st Cross,G & H Block, Gange Road, Kuvempunagar, Mysore–570023, India.

A B S T R A C T

A 120-year old heritage building, known as Farhmjee Contractor's Bungalow, in the city of Baroda in Gujarat (India) has been restored with meticulous planning, and deployment of appropriate skills and use of compatible materials during September 2002 to March 2004.It was an exposed brick masonry structure having beautiful carving, neat lines, perfect symmetry, exquisite domes and urns, and excellent artwork in the middle of greenery and open space. The present case study narrates the type and extent of damages suffered by the building, the concept of restoration and the course of implementation.

K e y w o r d s

Restoration, Masonry bungalow, Modified lime mortar putty, Anticorrosive treatment, Rain water harvesting

1.0 BACKGROUND

Baroda or Vadodara, referred to as the "sanskaar nagri" (the city of resurrection) of Gujarat in India, has many beautiful landmark structures which are now coming into limelight as heritage buildings. Situated on the commercial hub of the city, the Contractor's Bungalow is one such structure, which is a feast to the eye, a visual delight. Spread over about 800m^2 in the city's area, the bungalow built in neoclassical brick masonry, has many similarities with respect to art decor and frescos found in the then historical buildings.

About 120 years back, Farhamjee Cawasjee Contractor, who built the Contractor's Bungalow, started his career with the British Regency. He inherited his uncle's business who was into brick making, and the rest is history. His bricks were known for their superb quality. Apart from being used for the Laxmivilas Palace of Maharaja Sayajirao Gaekwad and Arts Faculty Building, these were used for building the six houses that Farhamji built for his descendents.

The restoration of one of these buildings was taken up as an ambitious restoration project by R.G.Rao and Associates, Mysore-specialists in heritage restoration works.

2.0 ARCHITECTURAL CONFIGURATIONS

The building originally was conceived as a residence by Mr. R. Chisholm, the legendary architect, a member of Royal Institute of British Architects. It appears to be a sincere effort to combine functionality with beauty and synthesis of form. It is a witness to Faramji's penchant for decorative motifs–usually patterned flowers and birds around the walls and on the ceiling of the house. It's a rectangular shaped building with a central courtyard, a tulsi plant in the middle and characteristic exposed brickwork which is still in a wonderful condition. The plan of the Bungalow complex with various side views of the bungalow and other components are shown in Figure 1.

The residential complex comprises the main building and the rear block. The whole building is symmetrical along its central axis, which cuts across the main building as well as the rear block. A closed verandah runs on the periphery of the main building, whereas an internal passage runs along the square courtyard in the rear block.

Although the two blocks are very different in all respects, the passages are interconnected in such a way that they make the building look like a single majestic structure.

The building has load bearing structure in both the blocks. The main building is a double storeyed structure with flat roofs whereas the rear block is a single storeyed structure with a pitched roof in timber and Mangalore tiles. Interestingly enough, the main building has quite a few interesting features such as domed roofs for stairs & bedrooms, semi-domed roofs for porch and a jack arch roof for main hall.

The flooring also has variety like wooden flooring for first floor hall & bedroom and the usual lime concrete and masonry arched floors for passages.

Main building facades are treated with urns, domes and artworks of varied intensity everywhere, while rear block remains just a functional structure. Interestingly, a toilet block projects out of the main building on the eastern side, and that also has a domed roof at second floor level. Surprisingly a concept of attached toilet existed in this building which is almost 123 years old.

* Corresponding author
Tel : + 91 9342101552
E-mail : saveheriatage@gmail.com; preserve@airtelmail.in

POINT OF VIEW

INTERNATIONAL
Journal *of* 3R' s

Vol.1, No.3, 2010, 135-137

SELF- HEALING OF CONCRETE – ITS EVOLUTION AND POTENTIAL

D. S. Mandal[a*]

[a]Civil Engineering Department, Jadavpur University, Kolkata -700 032.

A B S T R A C T

The cracks in the concrete are inevitable and can happen at any point of time depending upon the stresses developed in the structures. The micro cracks which appeared inside, propagate into larger cracks causing rapid deterioration of the structures and decreasing the service life of the structures. Repair of such cracks from externally with any repair material have some limitations starting from compatibility, surface preparation, inaccessible part of the structure and downturn which can be avoided with various autogenous healing agents of cementitious, polymeric and biotic. The present paper focuses the pros and coins of such self-healing agents. The need for further research for application of gene cloning in future to develop the high performance bacteria for self healing of cracks is also being highlighted. It gives an overall view of the journey of self-healing materials from past to future for achieving a durable concrete.

K e y w o r d s

Autogenous healing, Cracks, Encapsulation, Biomineralisation, Gene cloning

Cracks can occur during any stage of the life of a concrete structure. They can be formed due to the concrete material itself as in the case of volume instabilities such as shrinkage, creep or due to external factors such as external loading, harsh environmental exposure, poor construction practices or even design error. These cracks primarily reduce the mechanical performance and durability of concrete structures. Therefore, the development of concrete that can heal automatically such cracks partially or fully is now highly desirable. This will ensure a more durable structure by regaining the mechanical strength. Along these lines the phenomenon of self healing in concrete commonly known as autogenous healing has been identified for many years. It has been observed that some cracks in old concrete structures are lined with white crystalline material indicating the ability of concrete to self seal the cracks chemically. The reasons of such sealing have been categorized as a combination of further hydration of unreacted cement, expansion of concrete in the crack flank (swelling), crystallization by the carbon-di-oxide in air (calcium carbonate), closing of cracks by solid matter in the water (impurities) and closing of cracks by spalling of loose concrete particle resulting from cracking [1].

It is now a common practice to reduce the cement content in the concrete matrix from economic point of view. Therefore, the untreated cement in the mix will be less; thereby the possibility of autogenous healing is comparatively less.

Various practical methods are also available to repair the cracks externally. These are mainly polymer injection, pre-stressing, polymer wrapping. All of them are based on the addition of repair material from the outside. However, these methods have major limitations like necessity of regular inspection of the concrete structure to locate the cracks (i.e. Crack then Repair Method), availability of space to repair etc, fixing up a suitable repairing material for its compatibility. Although some systems are being developed to locate the cracks or highly stressed areas by providing suitable sensors in the structures.

However, the man made self healing ability of concrete known as autonomic healing is relatively new field of research. The first such system proposed by Dry [2] was to use a suitable healing agent encapsulated inside a micro tube and when a small crack forms the tube breaks the microcapsule releasing the healing agent and ultimately heals the crack just like polymers. The main advantage in this technique is instant repair of cracks as and when developed. Even the regular inspection is not needed to detect cracks. It may be mentioned that the healing agent that is encapsulated and the encapsulating method are the two important constraints in this system. The prerequisites of the healing agent include (a) low viscosity to ensure wide repair area, (b) a sufficiently strong bond between cracks surface and (c) adequate capillary forces to draw the agent into the cracks. Till date the most common healing agent are low viscosity epoxy resins, cynacrylatates (superglue) and alkali silica solutions used by different researchers. However, each healing agent has some disadvantages and thus needs further modifications. For example, the setting time of cynacrylates is too quick and thus the dispersion of the glues within the cracks may be insufficient. In the case of alkali silica solution, bond strength with the concrete is comparatively less but it is likely more compatible than polymer based counterparts.

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