Strengthening of Pre-Damaged RC Beams with Externally Bonded UHSCAC Overlay

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***Abstract*:- Investigations carried out on Pre-damaged RC beams strengthened with an overlay made up of ultra high strength cementitious algal composite (UHSCAC). The ultra high strength cementitious algal composite (UHSCAC) overlay was cast with 2% steel fiber and 20% of cement replacement by algal precipitate. In this study 3 beams were tested by four-point bending load. The control beam was tested till failure and remaining 2 beams were preloaded with 90% ultimate load of control beam. These 2 beams were tested after retrofitting with 5 mm and 10 mm thickness of ultra high strength cementitious algal composite overlay (UHSCAC) respectively. These overlays were bonded on the tension face of the beam using epoxy adhesive. All specimens were subjected to a four point test under load control in which load deflection values were recorded. An experimental study is presented where the retrofit ability of the ultra high strength cementitious algal composite (UHSCAC) is utilized to strengthen the pre-damaged RC beams. The mode of failure, enhanced strength, crack pattern and the load deflection behaviour of the tested beams are discussed. The results confirm the suitability of UHSCAC overlay to enhance the moment carrying capacity without retarding the ductility of RC beam. The algal precipitate in the overlay enhances the C-S-H formation and increase the flexural capacity of composite beam.**

Keywords: Pre damaged RC beams, UHSCAC overlay, Algal precipitate, C-S-H Formation, Epoxy adhesive.

1. INTRODUCTION

Existing concrete structures may, be found to perform unsatisfactorily for a variety of reasons. This could manifest by poor performance under service loading, in the form of excessive deflection and cracking, or there could be inadequate ultimate strength [7]. The performance of current techniques of rehabilitation and strengthening using externally bonded ultra high strength concrete overlay (UHSC) has been extensively investigated. The ongoing efforts to upgrade, strengthen, retrofit, and rehabilitate existing reinforced concrete (RC) structures, along with the development of advanced composite materials, led to the development of a new strengthening approach .These approach make use of strips made of fiber reinforced plastic (FRP) bonded to the tensile face of the member. The method has advantages, mainly due to the superior mechanical properties of the composite material and its applicability to broad range of structural members such as beams, columns, slabs, masonry, and walls [8,9]. The use of biological approach in concrete is also considered as a green technology as its production does not involve greenhouse gas emission. Therefore bacterial induced calcium carbonate (Calcite) precipitation has been proposed as an alternative and environment friendly way for improvement of strength of building materials [12].

Recently, to encounter the problem associated with the prevailing strengthening techniques, a new kind of fiber reinforced concrete matrix composite owing the remarkable tensile strength and crack width resisting properties is developed. It was reported that reactive powder concrete (RPC) has an outstanding flexural strength and very high ductility [10]. A thin precast strips of high performance fiber reinforced cementitious composite which is post poured on the damaged beams to retrofit. To repair the damaged structure the beam on flexure, shear or in combination with several configurations of strips were used that found to be very effective to retrofit [11, 2]. Xu et al. [6] studied on the performance of ultra high toughness cementitious composite layer to strengthen plain concrete beams found to be very effective on flexural behavior with variable thickness.

In order to improve the strength deformability and toughness of an Ultra High Strength Concrete (UHSC), a number of short steel fibers are embedded to restrain cracks in the matrix. UHSC consists of cementitious binders with

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 5 Issue 11, November-2016

steel fibers which provide a superior degree of ductility and crack width restricting property. Embedding steel fibers in the matrix enhances toughness and deformation of UHSC and to overcome the disadvantage of high brittleness [1].

In order to achieve the excellent integral behaviour or to avoid the interfacial debonding of the externally bonded overlay, surface should be roughened by sand blasting technique [3],[4],[6]. The experimental results showed that the acrylic based adhesive gives more bond strength under high loading conditions [5]. The present study, the pre-damaged RC beams are strengthened with an overlay made up of ultra high strength cementitious algal composite , the detail failure mode, crack pattern, flexural strength, and load deflection behavior is critically discussed and presented.

2. EXPERIMENTAL STUDIES

Tests were conducted on simply supported RC beams strengthened with UHSCAC overlay in tension face of the pre-damaged beams. A static load on four point bending platform was applied to study deflections, strains on overlay, crack patterns, flexural capacity and load deflection behaviour.

2.1 Details of materials, mixes and tested beams

Algal precipitate:

Figure 1*: Halimeda sp*

Figure 2: Algal precipitate

Halimeda sp.(Fig 1) is a calcareous form of green macro algae that grows throughout the world's tropical regions. Characterization studies were carried out using X-Ray Diffraction (XRD) and Scanning electron microscopy. From the XRD results, the presence of calcium and silicate components in the plant's precipitate was confirmed and the calcium carbonate produced was in the form of aragonite. In this work the algal precipitate was obtained by crushing the algae with mortar and pestle. This was made to fine powder by further grinding and sieved by passing it through 40 micron sieve mesh to obtain particles of <40microns(Fig 2). Thus obtained algal precipitate was used for replacement of cement in UHSCAC.

Epoxy Adhesive:

To improve the bond between the overlay (UHSCAC) and the damaged beams, all contacting surfaces were carefully cleaned and roughened. The overlays were bonded to the prepared surfaces of the damaged concrete beams with a commercial epoxy adhesive. The epoxy adhesive used as per the standard ASTM C 881-78, Type II, Grade 2, Class B+C. The adhesive were thoroughly mixed and applied to the tension side of the damaged beam by using small plate. To ensure good adhesion, pressure must be applied to the overlay during the hardening of the adhesive at 24 hours.

Casting of RC beam and UHSCAC overlay:

Concrete mixes were designed with the grades of compressive strength according to the Indian standards [IS 10262:2009 & IS 456:2000]. The mix were made of ordinary Portland cement 53 grade, natural sand, crushed aggregate size below 12mm and potable water, (Normal strength concrete, NSC). The NSC mix proportion by weight of cement, fine aggregates, coarse aggregates and water were taken as 1:1.669:1.856:0.45. The UHSCAC mix consists of cement, silica fume, Quartz sand, Quartz powder and water in the ratio of 1:0.25:1.1:0.4:0.23 respectively. The 20% of cement replacement by algal precipitate and steel fibers were added by 2% by the volume of concrete .The Super plasticizer was added by 3.5% of dry weight of binder. To enhance the density of mix, water cement ratio of 0.23 was adopted. The specimen preparation was strictly controlled to minimize the scatter in the test results. The NSC specimens were demoulded after 1 day and cured in a water tank at ambient temperature for 28 days.

The UHSCAC specimens were also demoulded after 1 day and immersed in water at ambient temperature for 2 days. They were then placed in an autoclave at 90°C for 2 days and in an oven at 200°C for 1 day. Thereafter they were air cooled for 6 hours and placed in water at ambient temperature for a further 1 day before testing. Compression and split tensile tests were carried out on cube specimens 70x70x70 mm (length x breadth x height) and cylindrical specimens of 50×100 mm (diameter x height) in the case of control UHSCC and UHSCAC. The average compressive strength and split tensile strength for control UHSCC are obtained as 122MPa and 20.7MPa respectively. For the case of UHSCAC the values are 129.16MPa and the split tensile strength of 21MPa.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 5 Issue 11, November-2016

The dimensions of the UHSCAC overlay were taken as 5mm and 10mm thickness ,100mm width and the length as 1500mm. Tests on three RC beams were conducted up to failure, one of them was taken as control beam and other two was strengthened beams with UHSCAC overlays of 1500mm length after partial damage of 90% (75kN) of failure load. The overall dimensions of the beam were kept constant for all specimens as 100mm wide 200mm high and 1500mm long. The typical details of RC beams are shown in Fig.3 a).

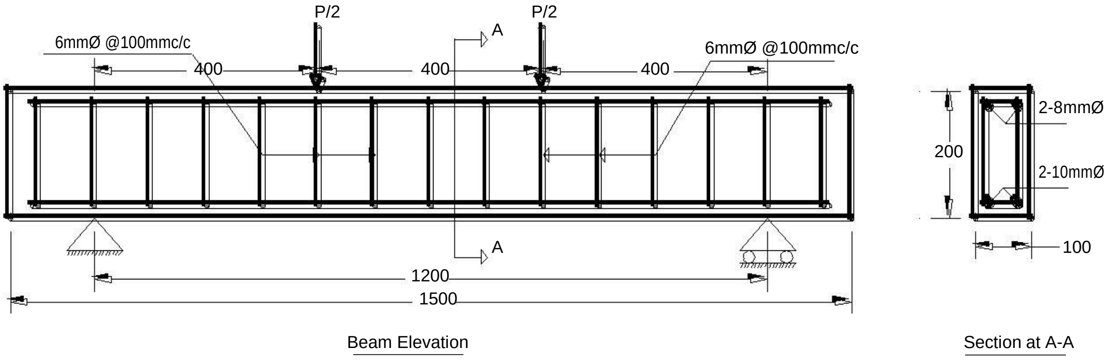


Fig 3a). Typical details of beam

Experimental setup and test procedures:

All beams were simply supported over a clear span of 1200mm and tested under four point bending, as shown in Fig 3 b).

Fig.3 b) Experimental setup

The load was applied using a servo controlled hydraulic actuator (400kN capacity) with a loading rate of 0.5mm/min (displacement approach) for control specimen and 1.0mm/min for strengthened beams.

2.2 Strengthening procedure

The preloaded beams were removed from the loading platform for strengthening. The tension face of the beam was roughened using sand blasting technique and was washed using water to remove dirt. The specimens were allowed to dry out and the commercially available epoxy was applied on the roughened surface maintaining the uniform thickness of 3mm. The UHSCAC overlay was then placed over the prepared surface of the damaged beam and compress with G-clamp to hold it strongly. The specimen was allowed to dry for 24hours to have better bonding. Fig. 4 shows the UHSCAC overlay to strengthen the damage beams.

Fig.4 UHSCAC overlay

3. RESULTS AND DISCUSSION

The failure mode of the RC_CON (control) beam is typical flexural failure. The first crack of the beam was observed at the load of 34 kN. Several major flexural cracks initiated at the constant bending moment zone before yielding the main reinforcement. The main reinforcement was found to yield at the load of 67 kN. The initiated flexural cracks gradually propagated to the full depth of the beams leading to ultimate failure followed by crushing of concrete at compression zone. The ultimate load carried by the beam at failure is 75 kN Moreover, several shear cracks were also formed during the experiment; however those were not responsible for the ultimate failure of the beam.

Fig 5 a) and b) shows the failure mode of strengthened beams RCUH20 (RC beam with5mm thickness UHSCAC overlay) and RCUH21 (RC beam with 10mm thickness UHSCAC overlay). Under loading, several flexural cracks were developed throughout the length of the beams. The first crack load for the tested strengthened beams RCUH20 and RCUH21were found to be 42 kN and 48.6 kN respectively.

Fig. 5 a) RCUH20

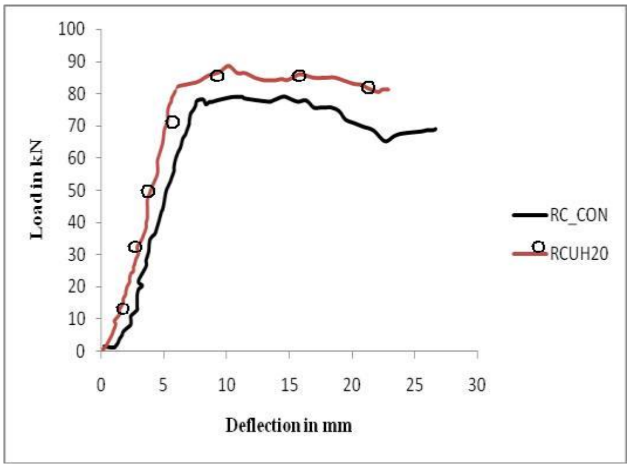
Fig. 5 b) RCUH21

The ultimate failure of beams occurred due to the flexural cracks initiated at the mid region of the beam which propagated to the full depth of the beam followed by crushing. Few shear cracks were also formed in the beam, however the contribution of those cracks for ultimate failure was found to be insignificant. Strengthened beams RCUH20 and RCUH21 failed in shear and flexure respectively. The load carrying capacity of the beams RCUH20 and RCUH21are enhanced by 16% and 7% compared to the control beam. The ultimate load carried by the tested strengthened beams RCUH20 and RCUH21 were found to be 87.4 kN and 80 kN respectively. The maximum measured crack width for the strengthened specimens was 3.5mm and 4mm for RCUH20 and RCUH21 respectively. Fig. 6 a) and b) shows load versus midspan deflection of the tested beam. The result presents the strengthening ability of the UHSCAC overlay over RC beams.

The first crack on UHSCAC overlay after strengthening on RC beams were observed at 48.6 kN and 51 kN for RCUH20 and RCUH21 respectively. Further 2-3mm widening of crack initiated at pure bending zone occurred at 73.4 kN and 79 kN on the strengthened beams RCUH20 and RCUH21 respectively. Debonding was not observed in both RCUH20 and RCUH21.The observed experimental results are given table 1.

TABLE 1. Observations from experiment

Beam	RC-Con	RCUH20	RCUH21
Pre-damage load, kN	N/A	67.5	67.5
Pre-damage load (%)	N/A	90	90
First crack load, in kN	34	42	48.6
Steel yield load in kN	67	74.25	73.21
Ultimate load in kN	75	87.4	80
Increased capacity (%)	N/A	16	7
Mid span deflection, mm	20.1	11.72	16.85
Failure mode	Flexure	shear	Flexure



6 a) Load Vs displacement curve for RC_CON and RCUH20

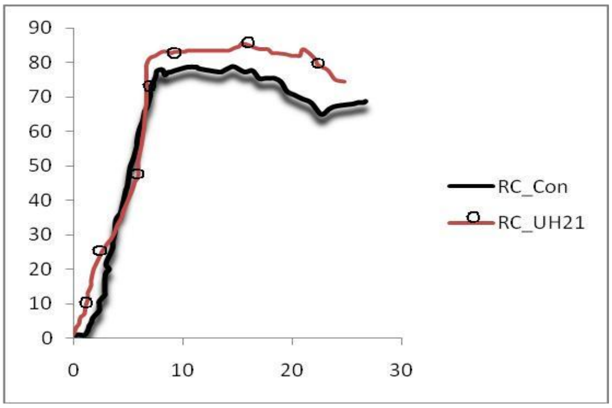


Fig 6 b) Load Vs displacement curve for RC_CON and RC-UH21

4 CONCLUSIONS

This study evaluates the flexural behavior of strengthened RC beams with severe pre-damage using UHSCAC overlay

The conclusions from the study are as follows:

1) The ultimate load carrying capacity of the strengthened beam RCUH20, RCUH21 is enhanced by 16%, 7% even after the pre-damage of 90% highlights the retrofitting ability of the UHSCAC overlay.
2) The UHSCAC overlay increases the first crack load, yield load and flexural stiffness of the beam. The first crack load enhanced by 23.5% and 42% respectively.
3) The other important thing is no debonding occurred in both RCUH20 and RCUH21.
4) The UHSCAC overlay casted with 20% of cement replaced with algal precipitate has enhanced the C-S-H formation and increase flexural behavior of beam.

The studies confirmed that strengthening of pre-damage RC beams using UHSCAC overlay could be a feasible solution for the strength deficient RC structure.

ACKNOWLEDGMENT

The authors wish to thank the supports given by Computational Structural Mechanics Group and structural testing laboratory staff members. This paper is being published with the kind permission of the Director, CSIR-SERC.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 5 Issue 11, November-2016

REFERENCES

[1] A. Ramachandra Murthy, Nagesh R Iyer, B.K Raghu Prasad, (2013), 'Evaluation of mechanical properties of high strength and ultra high strength concretes', Adv.Con. Constr., 1,(4), , pp.341-358.

[2] Alaee FJ, Karihaloo BL. (2003), Retrofitting of Reinforced Concrete Beams with CARDIFRC. J. of Composites for Construction,;7(3), pp.174-86.

[3] Bassam A. Tayeha, B H Abu Bakarb, M A Megat Joharib and Yen Lei Vooc, 2013. **"**Evaluation of Bond Strength between Normal Concrete Substrate and Ultra High Performance Fiber Concrete as a Repair Material". Procedia Engineering, vol.54, pp. 554 – 563.

[4] Bassam A. Tayeha, B H Abu Bakarb, M A Megat Joharib and Yen Lei Vooc, 2012. "Mechanical and permeability properties of the interface between normal concrete substrate and ultra high performance fiber concrete overlay". Construction and Building Materials, vol.36, pp. 538–548.

[5] Bo Gao a, Jang-Kyo Kim a, Christopher K.Y. Leung b, 2004. "Experimental study on RC beams with FRP strips bonded with rubber modified resins". Composites Science and Technology, vol. 64, pp. 2557–2564.

[6] F.A.Farhat, D. Nicolaides, A. Kanellopoulos, B.L. Karihaloo, 2007. "High performance fibre-reinforced cementitious composite (CARDIFRC) – Performance and application to retrofitting". Engineering Fracture Mechanics, vol. 74, pp. 151–167.

[7] Farshid Jandaghi Alaee and Bhushan Lal Karihaloo,(2003) " Retrofitting of Reinforced Concrete Beams with CARDIFRC " Journal of Composites for Construction, Volume. 7, No.3, Augest 1.

[8] Meier U, Deuring M, meier h, Schwegler G. Strengthening of structures with advanced composites. Alternative materilas for reinforcement and prestressing of concrete. Glasgow, Scotland: J.L. Clarke/ Chapman & Hall: 1993.

[9] Meier U. Post strengthening by continuous fiber laminates in Europe. Non-metalic (FRP) reinforcement for concrete structures (Proceedings of the Third International Symposium), vol, 1. Tokoyo, Japan: Japan Concrete Institute: 1997.

[10] Richard, P and Cheyrezy M,. 1995, Composition of reactive powder concretes. Cement & Concrete Research. 25 (7):1501-1511.

[11] S.L. Xu, N.Wang, X.F. Zhang, 2012. Flexural behavior of plain cement concrete beams strengthened with ultra-high toughness cementitious concrete layer. Materials & structures. 45, 851-859.

[12] Srinivasa Reddy V, Sreenivasa Rao D, Seshagiri Rao M V, Sasikala Ch.(2013) "Permeation Properties of Bacterial Concrete" Published in IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE) e-ISSN: 2278-1684 Volume 5,No .6 , PP 08-12 (Mar. – Apr).