Retrofitting of reinforced concrete beams using self-compacting concrete as jacketing material: A state-of-the-art review

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ABSTRACT

In this paper, the overall review about the change in strength parameters and ductility behaviour of reinforced concrete beams is discussed when reinforced concrete beams are strengthened with self-compacting concrete jacketing. The purpose of self-compacting concrete jacketing is to increase the strength of existing structural members to strengthen the damaged structural members or due to increase in service load on structural members. Various reasons causing damage to structural members are design errors, faulty construction, earthquakes, accidents, fire etc. Self-compacting concrete jacketing is used for repair and rehabilitation of damaged structural members. The discussion includes effectiveness of self-compacting concrete as jacketing material for overall enhancement of structural members.

Keywords: Retrofitting, Jacketing, Reinforced Self-Compacting Concrete, Fibre Reinforced self-compacting concrete, Steel wire mesh

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I.INTRODUCTION

Self-compacting concrete is a special kind of concrete that can percolate and fill voids in places where heavy reinforcement is provided and also fill corners of mould completely without the use of vibrators for compaction during process of placing concrete in the mould. Self-compacting concrete is highly fluidic in nature and it is suitably placed in difficult conditions and in sections with congested reinforcement. The development of self-compacting concrete started keeping in mind lack of uniformity and necessity of compaction by vibration in concrete by University of Tokyo, Japan in late 1980's.

Self-compacting concrete can be placed faster without mechanical vibration and less screeding which course reduction in placement cost. It makes more uniform structural surface finish with little or no remedial surface work. Self-compacting concrete reaches areas easily and restricted sections can be filled completely. Difficult

structures and shapes can be obtained easily by using self-compacting concrete. It provides better consolidation around reinforcement. Self-compacting concrete have better pumping ability. It gives high labour saving, cost saving by reducing the construction period. Easily placed in thin-walled elements with limited access. As skills of workers, the shape and amount of reinforcement bars or the arrangement of structures does not affect self-compacting concrete because of its high fluidity and resistance to segregation it can also be pumped to longer distance. The elimination of vibration leads to an improved concrete quality, decreased skilled labour and shortens the time needed for construction. It possesses the ability to moulded into any shape with the help of mould. It is used in congested areas where compaction equipment's cannot be used. Thus, reducing the cost of the structure to about one tenth of the total cost of structure.

Beams are one of the most important structural members which transfers the loads to the columns. The behaviour of beam in structures is very important since beam failures lead to structural failures. Replacement of the damaged structural elements is very difficult and may create a high risk to the overall structural integrity. Jacketing of a beam is needed when the load carried by the member is increased or due to mistakes in the design. Conventional retrofitting techniques, such as concrete and steel jacketing, have been used significantly for the repair and rehabilitation of reinforced concrete structures. The aim of this paper is to have a comprehensive literature review of the work done in the field of self-compacting concrete in order to get a better idea of the issues relevant to strengthening of reinforced concrete beams with self-compacting concrete used as jacketing material.

II. LITERATURE REVIEW

Constantin E. Chalioris et al (2012) [1] conducted a study for rehabilitation of shear damaged reinforced concrete beams using self-compacting concrete jacketing. Damaged beams were restored using reinforced self-compacting concrete and tested using 4-point loading system. Calculation is made on flexural strength and shear strength of strengthened tested beams. Evaluation of yield capacity and ultimate load capacity of jacketed beams is done.

Constantin E. Chalioris et al (2012) [2] deals with tests and analysis of self-compacting concrete jacketing for strengthening of shear damaged reinforced concrete beams. U-shape jacketing is provided to damaged beams to increase shear capacity of original beams. The strengthened beams are tested under four-point loading system. Test result shows ductile failure of strengthened beams and increase in overall performance of strengthened RC beams indicating efficiency of self-compacting concrete jacketing.

Constantin E. Chalioris (2013) [3] investigates efficiency of reinforced self-compacting concrete as jacketing material for retrofitting of damaged reinforced concrete beams under monotonic and repeated loading.

Experimental study included 12 beams. The size of beams is 1600 mm × 125 mm × 200 mm. U-form jacketing style has been used with small diameter steel bars and self-compacting concrete. The compressive strength and tensile strength of self-compacting concrete is 40.10 MPa and 3.5 MPa respectively. Result shows increase in load carrying capacity of jacketed beams by 35 to 50%. The ultimate shear load varies between 39.7 kN to 42.0 kN. All jacketed beams fail in ductile manner showing flexural response whereas original beams show brittle response at failure. This study concludes that use of reinforced self-compacting concrete as jacketing material for restoration and rehabilitation of damaged reinforced concrete beams is effective and reliable.

Constantin E. Chalioris (2014) [4] presents effective use of reinforced self-compacting concrete for repair and strengthening of under designed reinforced concrete beams. Experimental program consists of 20 RC beams. The beams are tested near failure and then strengthened. Result shows thin layered self-compacting concrete jacketing provide better structural performance than normal concrete jacketing. Full recovery of damaged RC beams due to previous loading with increase in strength and enhanced ductility capacity. The paper concludes that use of reinforced self-compacting concrete is an excellent methods for repair and rehabilitation for earthquake damaged structures.

Klaus Holschemacher et al (2017) [5] evaluates the use of steel fibre reinforced high strength light weight self-compacting concrete as jacketing material for strengthening of reinforced concrete beams. Result shows increase in peak load capacity is in range of 14% to 58% with 40 mm, 50 mm and 60 mm layers of steel fibre reinforced high strength light weight self-compacting concrete for strengthening of reinforced concrete beams. Application of steel fibre reinforced high strength light weight self-compacting concrete in tension zone of beam increases peak load by 33.1% and significant increase in stiffness of strengthened beams.

Xuhui Zhang et al (2018) [6] deals with strengthening of damaged reinforced concrete T-beams using self-compacting concrete as jacketing material. Experimental program consists of 8 reinforced concrete T-beams which are subjected to loading near failure and then strengthened using self-compacting concrete as jacketing material and test of strengthened beams conducted for flexural strength. Result shows enhancement in performance of strengthened beams in terms of flexural strength and stiffness. The flexural load capacity of strengthened reinforced concrete beams by using self-compacting concrete as jacketing material is being twice of flexural load capacity of initial reinforced concrete beams without any jacketing.

Abhilash CS et al (2019) [7] investigates the use of self-curing self-compacting concrete as a jacketing material for retrofitting of RC beams. In this paper, cement is being replaced by flyash and alcofine at varied proportions by weight of cementious material. The size of RC beam is 2800 mm × 150 mm × 300 mm. RC beams of 150mm X 250mm X 2000 mm overall and 150mm X 219mm X 2600mm effective will be casted. with different reinforcing conditions. The mechanical properties are evaluated at 3,7,28,56,90 days. Slump flow test, L-box

test, V-funnel test are conducted to check the quality of concrete as per set parameters. Several tests conducted for determining strength of hardened concrete such as compression test, split tensile test, acid attack and sulphate attack. Linear variation deflection transmission (LVDT) was used to note down the deflections of the test beams at three positions. One below mid- span and other two below the loading points. Result analysis is done on load carrying capacity of strengthened beams. Self-compacting concrete mix improves the flowability properties with increased rheology in terms of slump flow, V-Funnel and L-Box. It is concluded that to achieve better rheological properties of self-compacting concrete, Fly ash can be used as secondary cementitious material and Alcoffine as tertiary cementitious material in self-compacting concrete. The rate of strength development in Partially replaced concrete will be very slow at 3rd days and 7th day due to pozzalonic behaviour.

Mohamed Abu A. Maraq et al (2020) [8] presents flexural behaviour of reinforced concrete beams strengthened with steel wire mesh and self-compacting concrete. Experimental program consists of 18 RC beams, designed as per American building code ACI318. The size of control beam is 1200 mm × 150 mm × 100 mm and size of monolithic control beams and jacketed beams is 1200 mm × 200 mm × 160 mm. Out of 18 RC beams, 3 RC beams are used as control beams specimen, 4 are used as monolithic control beams specimen and rest 11 RC beams are used as jacketed beams specimen. The jacketed beams are further divided into group A and group B. Group A and group B jacketed beams are subjected to 110% and 163% load carrying capacity of control beams respectively, before its restoration using steel wire mesh and self-compacting concrete. Result shows use of use of steel wire mesh along with self-compacting concrete increase load carrying capacity, ductility, stiffness and cracking load of beams with respect to conventional beams. Reinforcement ratio of galvanised steel wire mesh increased in group B, and therefore the flexural recovery of strengthened beams of group B is more than group A. The paper concludes utilization of steel wire mesh and self-compacting jacketing is an efficient technique to strengthen RC beams in flexure.

Hamed Shabani Attar et al (2020) [9] analysis flexural and shear strengthening of reinforced concrete beams using fibre reinforced self-compacting concrete as jacketing material. Experimental program consists of 10 RC beams which are categorised into group A and group B. In group A beams, shear strength of strengthened beams is evaluated whereas in group B beams, flexural strength of strengthened beams is examined by providing high amount of shear reinforcement in this group. The study uses different variables in terms of steel fibre dosage, shear reinforcement, GFRP rebars and longitudinal ratios for all strengthened beams. Result shows failure mode changes to flexure in group B beams. The beams which are strengthened with GFRP rebars for flexural strengthening shows combination of shear and flexural modes at failure.

Nuroji et al (2020) [10] deals with behaviour of reinforced concrete beams after jacketing using self-compacting concrete. Experimental investigation includes casting of control beam having size 125 mm × 200

mm with M20.3 grade of concrete and strengthened beam having size 200 mm × 300 mm with M23.9 grade of concrete. Beams are tested under two-point loading system. Result shows that sectional enlargement of strengthened beams increases load carrying capacity and stiffness of beams. Moment capacity of strengthened beams becomes six times more than capacity of control beams. Stiffness performance of strengthened beams becomes seven times more than performance of control beams.

Iraj Rahmani et al (2020) [11] studies the effect of steel fibre reinforced self-compacting concrete as a jacketing material for strengthening of reinforced concrete beams. Experimental program consists of 25 RC beams having variables in type of concrete, grade of concrete, use of reinforcement bars and steel fibres. Strengthened beams are tested under three-point loading system in terms of load-displacement values. Result shows increase in load bearing capacity of strengthened beams by 7.4 times to reach yield load and 5.1 times to reach ultimate load. The result alsop concludes that combination of steel fibres and steel bars reduces cracks and create better bonding between reinforcement and concrete. Concentration of cracks appeared in middle of span and there is reduction in rate of increase in crack length due to better distribution of stress.

Bassam A. Tayeh et al (2020) [12] investigates use of self-compacting concrete and steel welded wire mesh for strengthening of reinforced concrete beams. Experimental program consists of 3 control beams, 4 monolithic beams and 11 strengthened beams. Strengthened beams are divided into two groups on basis of steel wire mesh and bonding techniques. Result shows that strengthening techniques improves flexural capacity of strengthened beams.

K. Rajesh Kumar et al (2021) [13] evaluates the structural performance of fibre reinforced self-compacting concrete as jacketing material for strengthening of corroded reinforced concrete beams. Experimental investigates includes beams having size 700 mm × 100 mm × 300 mm. Glass chopped fibres and polypropylene fibres are used as steel reinforcement in self-compacting concrete and their compressive strength, flexural strength, mechanical properties are evaluated. Result findings shows use of fibre reinforced self-compacting concrete in strengthening of RC beams don’t show any harmful effect on structural properties. Result concludes that use of glass fibre in self-compacting concrete increases compressive strength by 0.06% and flexural strength by 15.4 % whereas use of polypropylene fibre in self-compacting concrete increases compressive strength by 0.1% and flexural strength by 40.8% in comparison to plain self-compacting concrete used as jacketing materials for strengthening of reinforced concrete beams. Structural performance of strengthened RC beams is enhanced in terms of flexural load capacity, stiffness, ductility and ultimate energy because of using fibre reinforced self-compacting concrete as jacketing material.

III. CONCLUSION

On the basis of results obtained from various literatures mentioned in this study, the conclusion made is that self-compacting concrete jacketing leads to a uniformly distributed increase in strength and stiffness of RC beams. The load carrying capacity of RC beams strengthened with self-compacting concrete jacketing is higher than RC beams strengthened with normal concrete. Significant improvement in durability of damaged beams and increase in total stiffness of beams. No sign of delamination is been seen in strengthened specimens between existing concrete and self-compacting concrete. Use of dowel bars, connectors enhance the bond between existing concrete and self-compacting concrete. Fibre reinforced polymers used as reinforcement in self-compacting concrete enhances the strength, ductility, and energy absorption capacity of strengthened RC beams. The self-compacting concrete used as jacketing material is efficient and effective technique that can withstand large axial load and impart high ductility.

Table 1: Summary of studies on strengthening of reinforced concrete beams using self-compacting concrete jacketing

S/N	Study	Jacketing material	Effect on ductility	Effect on strength	Effect on stiffness
1	C. E. Chalioris et al [1]	SCC	Increased	Significantly Increased	Increased
2	C. E. Chalioris et al [2]	SCC	Increased	Significantly Increased	Increased
3	C. E. Chalioris et al [3]	SCC	Increased	Significantly Increased	Increased
4	C. E. Chalioris et al [4]	SCC	Increased	Significantly Increased	Increased
5	K. Holschemacher et al [5]	SFR-HS-LW-SCC	Highly Increased	Highly Increased	Highly Increased
6	Xuhui Zhang et al [6]	SCC	Increased	Increased	Increased
7	Abhilash CS et al [7]	SC-SCC	Increased	Significantly Increased	Increased
8	Mohamed Maraq et al [8]	SWM-SCC	Highly Increased	Increased	Increased
9	Hamed S. Attar et al [9]	FRP-SCC	Highly Increased	Highly Increased	Increased
10	Nuroji et al [10]	SCC	Significantly Increased	Significantly Increased	unchanged
11	Iraj Rahmani et al [11]	SFR-SCC	Highly Increased	Highly Increased	Increased
12	Bassam A. Tayeh et al [12]	SWM-SCC	Significantly Increased	Highly Increased	unchanged
13	K. Rajesh Ku et al [13]	FRP-SCC	Highly Increased	Highly Increased	Increased

IV. ACKNOWLEDGMENT

I would like to express a deep sense of gratitude to all the scholars, authors and publishers whose articles and journals are cited and from that valuable data was reviewed and discussed for completing this review paper.

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The study is relevant to the theme "engineering and technology" of Shodh Shikhar research festival as the research paper is related to latest technology and materials used in repair and rehabilitation of damaged structures in the field of civil engineering. The paper discusses the comprehensive literature review of the work done in the field of strengthening structural members with use of self-compacting concrete.