A Comprehensive Review on Retrofitting Concrete Structures with Reactive Powder Concrete

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ABSTRACT
Recent advancement are made in the retrofitting techniques to enhance the characteristics like safety, serviceability and restorability of the structure which are susceptible to damage. More recently, there has been an increased research attention towards advanced techniques which emphasizes on the use of reactive powder concrete (RPC) for maintaining the existing as well as the new structure. RPC is an ultra high performance concrete (UHPC) which is a composite material formed by using Portland cement, silica fumes, quartz sand, steel fibre and super plasticizers. RPC as a material can be used at elevated temperatures where it will serve high bond strength and durability with normal concrete than any other retrofitting material. There is no effect of thermal cycling up to certain degrees on Reactive Powder Concrete therefore it can be used in hot weather condition. This paper is an overview of previous studies done in the field of retrofitting of structure using different techniques and highlights the advantages of RPC as a retrofitting material.

KEYWORDS: Retrofitting, Reactive powder concrete, Jacketing, FRP, Silica fumes, Steel fibres UHPC.

I. INTRODUCTION
Retrofitting of the existing structure means to improve the performance of the structure by escalating and strengthening the structural element or the whole structure. Retrofitting of the structure is done for improving structural properties of either a damaged structure to take the existing load safely or to enhance its structural properties to take an additional load. Retrofitting can be done globally or locally depending upon the extent of damage. Global retrofitting includes various means such as addition of structural walls for taking the structural loads, base isolation for preserving the structure from high intensity transverse load and use of steel bracing systems to improve the overall stability of the structure as well as its tensile strength. This all adds up to make the structure globally strong. Local retrofitting enhances the performance of individual segments of structures. This uses the techniques such as jacketing the members, wrapping of FRP and CFRP sheets, reactive powder concrete, etc.

Reactive powder concrete can improve the strength, durability and ductility of concrete structure susceptible to damage. In RPC, water content is reduced by using super plasticizer whereas steel fibres are used instead of coarse aggregate and highly refined silica fumes are used to enhance the adhesion properties of the mix. The low permeability is achieved using finer material there-by making it less porous and giving the concrete a dense compact structure which in turn also enhances its ductility.RPC has gained a lot of attention as a retrofitting material because of its very high strength, superior toughness, a good bonding strength and extreme durability. RPC gives the flexural and compressive strength in the range of 30-50 MPa and 200-800 MPa respectively and Young's modulus in the range 50-60 GPa. Thus, it can be used as a retrofitting material in retrofitting techniques. RPC can also be used to improve the seismic performance of the structure, for increasing the corrosion resistance, as a replacement of steel in compression member giving it a property of light weight members as compared to conventional members.

II. LITERATURE REVIEW
Vaghani et al. (2014) studied advanced retrofitting methods available for reinforced concrete structures which include general strengthening techniques, jacketing of existing beams, columns or joints, use of friction damper, use of fibre reinforced cement and steel bracings. The study suggested that jacketing is better for columns but not effective for beam or slab. They also concluded that the selection of retrofitting technique is a complex procedure and is represented by technically, financially and sociological considerations. Factors influencing the determination of retrofitting method are the type of structure, amount of damage, quality of the material, etc.

An He et al. (2017) performed test on column retrofitted with RAC (recycled aggregate concrete) in steel jacket retrofitting of column as an infill concrete and performed finite element modelling in ABAQUS. He concluded that strength, stiffness and durability of column specimen is greatly enhanced through steel jacketing approach with RAC.

ABD–Elhamed et al. (2015) performed test on damaged reinforced concrete beam having deformation retrofitted using jacketing of steel wire mesh & steel plate. He concluded that the strengthening by using jacketing with steel wire mesh with additional steel plate increase the ultimate load capacity of reinforced concrete beam. If the structure fails to meet the design criteria and withstand the design load, designer can increase steel wire mesh as well as cross section of additional plates to enhance the ultimate load capacity.

Sheikh (2002)did research on application of FRP in concrete structure and its effectiveness in enhancing structural performance in term of strength and ductility. In his research use of FRP on beam, slab, wall and column was investigated. He concluded that retrofitting using FRP tends to provide a feasible solution as a rehabilitation technique for strengthening & repair works and also improves the flexural strength of damaged slab, provides seismic resistance to columns and shear resistance to damaged beam.

Shahawy et al. (1996)studied the performance of structurally damaged concrete slabs in terms of flexural strength, deflection, cracking behaviour which was retrofitted with CFRP laminates. He concluded that strengthening of altogether split sections by holding CFRP laminates was structurally proficient and that the retrofitted slabs are re-established to strength and stiffness almost equivalent to or more noteworthy than the first undamaged slabs. The outcomes demonstrate that the retrofitted slabs kept up the sufficient auxiliary trustworthiness and composite activity at all phases of testing up to failure. He concluded that retrofitting using CFRP enhance the significant strengthening effect, flexural capacity, and retention of composite structure.

Chezrezy et al. (1995) studied the micro structural properties of RPC and conducted different tests such as mercury porosimetry, X-ray diffraction and thermo gravimetric analysis. He also examined the temperature effects on heat of hydration and pozzolanic reaction. It is clear from the results that RPC microstructure depends on the temperature conditions. The study show that the change in the microstructure of RPC with an increase of temperature.

Alaa (2013) studied the behaviour of mechanical properties of economical type RPC on elevated temperature like 300 ˚c, 400 ˚c and 500 ˚c for 2-4 hours. He used cheap steel fiber and local river sand to make the RPC economical. The variables in the experiments were cement content, steel fiber content, heating temperature and its duration. From the results he concluded that RPC can be used at high temp up to 300 degrees but the strength is reduced up to 55%. The use of RPC is not suitable for temperature higher than 300 degrees.

Salah et al. (2013) performed test on four different concrete mix prepared using different aggregates, same cement content and different water and cement ratio. Super plasticizers are used to achieve high performance concrete of grade M60 and added 10% silica fume to study the performance of concrete. He concluded crushed aggregates gives high strength concrete and addition of 10% silica fume develops stronger bond between aggregates and cement.

Yin-wen chan et al. (2004) performed experiments to test the silica fume effects on bonding. He used varying compositions from 0-40% of silica fumes in the mix proportion. He found out that addition of silica fumes to the RPC mix extremely enhance the binding characteristics of steel fibre-matrix bond. The result showed the optimum silica fume-cement ratio were between 20-30% and at 30% the pull-out energy and bond strength increases by 100% and 14% respectively.

Bakar et al. (2014) studied silica fume effects on adhesion properties of RPC with the normal concrete.The results of the investigation showed that the presence of the silica fume in the ITZ (interfacial transition zone) altogether improves the bond strength between reactive powder concrete and normal concrete substrate. He also concluded that it expends calcium hydroxide, which is in participation in the ITZ, and makes the zone tough, uniform and denser.

Momayez et al. (2005) studied the effect of different types of bond strength test on the bond strength of concrete substrate and repairing material. Methods used were slant shear, pull off test, Bi-surface shear test and splitting prism. The specimens were retrofitted with 6 different retrofitting materials and were tested under different state of stresses. Bond strength was relying on the test utilized and diminishing appropriately for slant shear test, pull off test and Bi-surface shear tests. Bond strength improved with the usage of silica fumes and roughness of the surface.

Miguel et al. (2014) studied the bond characteristics between Normal concrete (NC) and High Performance Concrete under varying environmental conditions and stress configurations and performed split tensile test considering the freeze thaw cycle and found the age of the bond using slant shear test and pull off test under varying roughness of degree of substrate, different wetting condition and exposure to freeze thaw cycle of concrete substrate. Results of this investigation show the bond characteristics between UHPC and NC are exceeding the recommended capacities.

Liu et al. (2007)performed test on cylindrical specimens retrofitted with highly flowable reactive powder mortar and compared results with specimens retrofitted with Epoxy resin. From the results, the strength of specimen retrofitted with RPM and Epoxy resin are same. The rebar pull out forces and mode of failure of the specimen retrofitted using reactive powder mortar were affected by the cross section of rebar used. Further he concluded that RPM is an effective retrofitting material for concrete structures.

Roux et al. (1996) did comparative study on the durability of RPC and NC of grade M30 and M80. He concluded that the RPC possesses excellent resistance to aggressive agents as compare to NC because of its low porosity and excellent compactness. The results obtain was absence of pores exceeding diameter 15nm. Due to its extremely high resistance to aggressive agent the durability of RPC was excellent and there was an increase in life of structure constructed with RPC as compare to NC.

Abraham et al. (2016)performed test on Reactive Powder Concrete and High Performance Concrete and compared its physical and mechanical properties as well as performed durability studies. The result showed that Reactive Powder Concrete gives more compressive and flexural strengths than High Performance Concrete. He stated that Reactive Powder Concrete has excellent durability properties and mechanical properties than conventional HPC, and in some applications Reactive Powder Concrete could even replace steel. Reactive Powder Concrete gives advantage of waterproofing and durability characteristics because of its ultra-dense microstructure.

Lee et al. (2006) studied durability of reactive powder concrete as a repair material for concrete member and tested them under freeze thaw cycle using acceleration deterioration test. He performed NDT test, bond test and rebar pullout strength test on the specimen before and after aging. The results show that Reactive Powder Concrete was an excellent repair material as it possesses high bond strength, strengthening effect and durability as normal concrete. The main findings were compressive strength increases 200% and 300% for 10mm and 20mm thick layer respectively and flexural strength increases to 150% to 200% for 10mm and 20mm thick layer respectively.

Graybeal et al. (2007) studied about the durability of the UHPC and compared it with normal concrete. Different curing treatment were applied to the UHPC which significantly improved the durability property of the concrete. Different durability test were performed such as chloride ion penetration, scaling, abrasion resistance etc. The result showed that this increased the degree of hydration thereby increasing the permeation resistance.

Anila et al. (2015) did the comparative study between Normal concrete column and modified RPC column and perform compressive strength test. He tested the durability and compressive strength of columns. He concluded that the modified RPC column shows higher compressible strength. She suggested modified RPC should be provided as cover to normal concrete columns.

Duget et al. (1996) performed compressive and flexural strength test to study the mechanical properties of RPC. He studied the critical stress factor and fracture energy by applying compliance method. He concluded that, In case of RPC200, compressive strength 200 MPa, fracture energy 40,000 J/m^2 and flexural strength 32 MPa is the result of its high compactness which was achieved by using silica fume, quartz sand and super plasticizer. The optimum fibre content in RPC200 was taken as 2-3% and increase in fibre content makes drop in fracture energy. In case of RPC800, pressurization and high temperature condition makes a material which displays strain hardening at low load. In damage phase, RPC limits sudden failure of structure.

Farhat et al. (2007)studied performance and application of HPFRC as retrofitting material. He utilized thin strips to retrofit the damaged beam which was subjected to thermal cycling. He casted beam specimen of size 100mm×100mm×500mm, cylinder of 100mm diameter and two thin strip of thickness 20mm and 16mm. The results shows that mechanical properties are unaffected by thermal cycling. A HPFRC strip improves the serviceability and flexural strength of the beams. This technique of retrofitting can be successfully used in hot climate.

Wassam et al. (2013)studied utilization of ultra high performed fibre for retrofitting. He studied the different properties of UPFRC like tensile strength, durability, flexural strength and bond strength and durability as compare to normal concrete. He concluded that UPFRC possesses high retrofitting potential in flexural and compressive strengthening and high bonding strength and bond durability. Due to the extremely low permeability, very high strength and excellent mechanical properties UPFRC is suitable for overlay material that is capable of mechanical loading and severe environment. The result of slant shears test shows those UPFRC possess high bond durability and bond strength with normal concrete as compare to other concrete.

Alaee et al. (2003) studied suitability of HPFRC with respect to other technique such as FRP and Steel wire mesh and necessary technology for the mix design of HPFRC. He perform test on two different type of beam differing only by the reinforcement. Experiments were carried out in 2 stages. He concluded that Durability, serviceability and flexural strength of the damaged structure are improved by HPFRC bond strip. It did not suffer from drawbacks of existing techniques such as mismatch in retrofitting material and concrete.

Chang et al. (2006)performed test on damaged concrete beam retrofitted with Reactive Powder Concrete to know its suitability as a retrofitting material by evaluating its compressive and flexural strengths. The fresh RPC was cast into cylindrical moulds of diameter 50 mm and length 100 mm and cured in ambient laboratory environment for 24 hours. He concluded that the flow of Reactive Powder Concrete is between 155-205%. He used Reactive Powder Concrete in from of strips of size 10mm and 20mm to retrofit the damaged concrete beam. Cylindrical specimen were wrapped with strips and tested for compressive and flexure strength. Result shows that cylindrical specimen retrofitted with 10mm and 20mm strips, the average increase in compressive strength of composite structure was 28% and 40% respectively and average increase flexural strength was 90% and 120% respectively. He concluded that strengthening effects of Reactive Powder Concrete on flexural strength was more significant than the compressive strength.

Sundaravadivelu et al. (2017) studied the behaviour of RC beams retrofitted using reactive powder concrete. To find out the ultimate load and modes of failure, reinforced concrete beams were casted with M30 concrete. The size of beams were 1200×100×200mm. The beams were tested in labs under two point loads. The experimental results showed that RPC can be used as a material for retrofitting. To bond the old concrete to the new concrete Nitobond EP Epoxy adhesive was used. Further he concluded that this method can be used to retrofit the structures damaged under flexure and there will be no debonding between the old and the new concrete.

III. CONCLUSION

This paper is an overview of previous studies done in the field of retrofitting of structure by using Reactive Powder Concrete as retrofitting material. Silica fume can act as a binder material and addition of silica fume to cement content develops a stronger and denser interfacial transition zone. The microstructure of RPC depends on the temperature conditions and with change in the temperature conditions the microstructure of RPC changes. Reactive Powder Concrete gives more significant increase in flexural strength than the compressive strength so it is most effective in retrofitting of beams than column.

Reactive Powder Concrete as a retrofitting material can give a better bond strength with normal concrete, there-by neglecting durability issues for long run. There is no effect of thermal cycling on Reactive Powder Concrete therefore it can be used in hot weather conditions. RPC can be used at high temperature up to 300 degree Celsius. It is not recommended to use over 300 degree Celsius. The bond strength of NC and RPC is excellent and it does not depend on the surface conditions. Basic treatments that evacuate dust and debris may be adequate to acquire a high bond.

Reactive Powder Concrete as a multifunctional material can be used as a foundation for development of stations for launching rockets carrying spaceships and for concrete structures in nuclear power stations due to its ultra-dense microstructure. Furthermore, studies can be carried out on RPC as a retrofitting material.

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