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A Review on Behaviour of Fire Damaged Cement and Geopolymer Slabs Retrofitted with GFRP laminates

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ABSTRACT:
Many of the existing reinforced concrete structure around the world are in desperate need of rehabilitation, repair, retrofitting and reconstruction due to lack of detailing, beam-column joint failure, or by exceptional events such as accidental fire, earthquake, etc., Fibre reinforced polymer (FRP) composite has been accepted in the construction industry as a promising substitute for repair and retrofitting of RC structures. This paper provides the literature review on performance of fire damaged cement and geopolymer reinforced slabs retrofitted with Glass Fibre Reinforced Polymer (GFRP) laminates. This paper takes various factors into considerations such as different wrapping configuration, strengthening techniques, different loading conditions in different structural elements as experimental, analytical and theoretical studies.
KEYWORDS: *FRP, GFRP, geopolymer concrete, fire damage, blast loading.*

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I. INTRODUCTION

Repairing and strengthening of existing reinforced concrete (RC) structures is important not just for extending their service life, but also for retrofitting them after they have been damaged by unusual events such as fire or earthquake. The use of composites to retrofit reinforced concrete slabs is becoming a popular option in the construction industry. Repair, strengthening, and retrofitting of RC structures is becoming more common as the cost of new construction rises. A new structure composite technology that uses Fibre Reinforced Polymer (FRP) has recently emerged as very practical tool for strengthening and / or retrofitting of concrete structures. Because of their high strength-to-weight ratios, ease of handling and application, which eliminates the need for heavy equipment, fast installation, and the fact that they do not rust, FRP composites have been widely used for strengthening concrete structures as externally bonded reinforcement. FRPs come in a variety of forms, including Carbon FRP, Glass FRP, Basalt FRP, and Aramid FRP. External FRP bonding with an epoxy compound for RC structure strengthening has gained a lot of attention in recent years. External FRP bonding with an epoxy compound for RC structure reinforcement has gained a lot of attention in recent years.

II. LITERATURE REVIEW

The main focus is on the use of GFRP laminates to strengthen fire-damaged conventional and geopolymer reinforced concrete slabs. To fully utilise the effectiveness and properties of GFRP in the strengthening process, the behaviour of GFRP reinforced concrete elements, ductility, flexural capacity, and other parameters were investigated using data gathered from various journal papers in various approaches and aspects.

2.1 FRP STRENGTHENING TECHNIQUES

The FRP composite is a polymer with fibre reinforcement. FRP has received much interest as a cost-effective method of strengthening and/or retrofitting concrete structures.

Almusallam (2006) investigated the durability of reinforced concrete beams strengthened with GFRP laminates in varied environmental conditions. GFRP sheets affixed to beams and exposed to various curing conditions (NaOH, NaCl, and tap water) for 6–24 months showed no degradation in imparting strength and stiffness to strengthened beams. Exposure to sun radiation has no effect on the performance of GFRP sheets (containing UV rays). However, if GFRP sheets are exposed to solar radiations for an extended period of time, the degrading effect of such radiations (especially UV rays) cannot be denied. In general, FRP enhanced specimens demonstrated a significant improvement in flexural strength and ductility of RC beams.

Chen and Wan (2008) concluded that Except for CFRP, which has a high modulus of elasticity, it was observed that when a cross shape strengthening scheme was adopted, there was hardly no strengthening impact for an RC slab. When two layers of BFRP were used, there was a modest improvement. In ANSYS simulation, this had been validated. As a result, it is critical to select a suitable FRP material system for strengthening an RC slab, such as high modulus FRP, in order to achieve a satisfactory strengthening effect.

Ludovico et al (2008) concluded that the deformation capacity of the structure has likely been increased since the damage of retrofit structure was significantly less than the damage of "as-built" structure under the seismic input. The GFRP laminates greatly increased the structural global deformation capacity without compromising its strength. The laboratory research revealed that composites could be a viable alternative to traditional approaches.

Haddad et al (2010) investigated the use of fibre composite materials to repair heat-damaged reinforced concrete slabs. The test result showed that the slabs repaired with CFRP, GFRP, and steel fibrous grout layers surpassed the ultimate load capacity of the control slab by 158 %, 125 %, and 84 %, respectively. All the repair techniques proposed in this study may be considered as promising methods for restoring the flexural capacity of heat damaged RC slabs.

Zhishen et al (2010) examined the tensile fatigue behaviour of FRP and hybrid FRP sheets in an experimental setting. The failure mode of composite coupons is influenced by the fibre's tensile modulus, according with test results. Furthermore, the composites fatigue failure is caused by progressive damage propagation. In comparison to a homogeneous basalt composite, the fatigue resistance of carbon-basalt hybrid composites improves dramatically, whereas the resistance of carbon-glass hybrid composites does not.

Vasudeva and Kaur (2016) studied the retrofitting of RC beams with GFRP sheets. When retrofitted beams were compared to control beams, the load at the initial fracture and at ultimate failure increased. It was also indicated that flexural retrofitting be done at the same time as shear retrofitting. Furthermore, in the case of ultimate flexure and shear failure, retrofitting in shear zones was found to be the most effective.

Meikandaan and Murthy (2017) conducted an experimental investigation on the use of GFRP laminates to retrofit reinforced concrete beams. The result indicates that the reinforced cement concrete (RCC) pre-loaded beams covered with 50mm wide GFRP overlays along the entire length of beam performed better in terms of decreasing deflection than beams wrapped with 400mm wide GFRP overlays at the middle bottom of the beam.

Meikandaan and Hemapriya (2017) conducted an experimental investigation on the use of externally bonded GFRP sheets to strengthen shear deficient RC beams. The test results show that the GFRP system strengthening technique is suitable and can increase the shear capacity of beams, as well as being the most appealing and cost-effective method of concrete repair and strengthening. The use of GFRP laminates improves load carrying capacity, inhibits crack formation, and increases the energy absorption capabilities of beams reinforced with GFRP laminates.

Meikandaan and Murthy (2017) investigated the Flexural behaviour of RC beams wrapped with GFRP sheets. The test results show that by strengthening the beam at the soffit, the initial flexural crack appears at a higher load. Further, by strengthening the beam up to the neutral axis, the ultimate load carrying capacity of the beam is not increased significantly, and the cost is almost three times that of a beam strengthened only at the bottom.

Soltani et al (2020) experimentally investigated the Dynamic performance enhancement of RC slabs by steel fibres versus externally bonded GFRP sheets under impact loading. The findings show that increasing the GFRP in the bottom layer improves the performance of RC slabs under impact loads. The experimental data were used to validate the numerical simulation based on the LS-DYNA programme, and a reasonable agreement was found between the experimental results and the numerical modelling in terms of maximum displacement, acceleration, and failure pattern.

Harith et al (2020) investigated the flexural strength of continuous reinforced concrete beams strengthened or repaired with CFRP / GFRP sheets. The test results indicate that in both the positive and negative bending moment zones, there is a good ratio between the quantity of CFRP/GFRP sheets. At both the positive and negative bending moment zones, an ideal strengthening thickness exists.

According to the research, FRP laminates can assist improve the load-bearing capability of damaged structural components. It also increases the structure's overall deformation capability. Furthermore, the fibre structure is critical in strengthening structural elements that have been damaged.

2.2 FIRE INSULATION

The research and practise of minimising the negative consequences of potentially destructive fires is known as fire protection. It entails research and development, production, testing, and deployment of mitigating devices, as well as the study of behaviour, compartmentalization, suppression, and investigation of fire and related emergencies.

Williams et al (2006) performed experimental and numerical study to investigate the performance in fire of insulated FRP-strengthened concrete slabs. According to the results of the fire tests, having enough insulation thickness is critical for avoiding cracking and preventing possible delamination of the fire protection layer and concrete cover.

Hawileh et al (2015) investigated the temperature effect on the mechanical properties of carbon, glass and carbon-glass FRP laminates. Based on temperature range and type of FRP laminates, three different failure mechanisms were reported in this study: brittle fiber ruptures, epoxy adhesive loss followed by sheet splitting, and fibre rupture. When compared to the regularly used C and G sheets in strengthening reinforced concrete structural elements, the hybrid CG laminate preserves its stiffness up to 250^{o}C and exhibits greater fire resistance at service load because its elasticity modulus showed less deterioration at elevated temperature.

Jafari et al (2019) investigated the effect of fibre configuration and thickness on tensile behaviour of GFRP laminates subjected to elevated temperature. According to the observations, laminates with greater thickness performed better in terms of ultimate load capacity due to the outer layer's protection; the modulus of elasticity was also less sensitive to heat. The results revealed that, of all the parameters, an increase in temperature had the greatest impact on the specimens.

According to the observations, adequate fibre thickness is a vital criterion for preventing cracking and delamination. In addition, the hybrid FRP laminates outperformed the regular FRP laminates.

2.3BLAST LOADING

The blast explosion is caused by pressure, a vehicle bomb, or quarry blasting near or within the structure. The behaviour of structural components subjected to blast loads has been the matter of scientific endeavour in recent years due to various accidental or deliberate events.

Razaqpur et al (2006) conducted experimental investigation on blast loading response of RC panels with GFRP laminates. The results of the tests revealed that the retrofitted panel outperformed the non-retrofitted panel. One of the retrofitted panels entirely crumbled, while none of the non-retrofitted panels were damaged in the same way. The findings of this study suggest that the GFRP retrofit may not be appropriate in all situations.

Wu et al (2009) investigated the blast resistance of reinforced concrete slabs. When exposed to a same blast force, the plain Ultra High Performance Concrete (UHPFC) slab experienced less damage than the RC slabs, indicating that UHPFC is a more effective material for blast design. In addition, the performance of Ultra Reinforced High Performance Concrete (RUHPFC) slabs outperformed all other forms.

Almustafa and Nehdi (2021) studied the Machine learning prediction of structural response for FRP retrofitted RC slabs subjected to blast loading. The study found that using ML methods to estimate the behaviour of FRP-strengthened RC slabs under blast loading was a strong contender to the current state of the art. Furthermore, the ML model was able to forecast maximum displacement more precisely with much less technical considerations when compared to existing SDOF model predictions.

According to the study, FRP retrofitting may not be efficient under blast load, and the FRP strengthening approach may not be viable in all circumstances. The outcomes of the machine learning prediction were similar to those of the experimental results.

2.4GEOPOLYMER CONCRETE

The production and manufacturing of cement concrete releases a large amount of CO2 into the atmosphere, causing an ecological imbalance and loss of natural resources. A novel binding substance known as geopolymers has evolved to decrease the detrimental consequences.

Zhao and Sanjayan (2011) compared the performance of Geopolymer and Portland cement concretes in a fire simulation. Two simulated fire tests were done in this study: a rapid surface temperature rise exposure test and a standard curve fire test. Spalling was not observed in geopolymer concretes (GPC) in either type of test, however spalling was found in the companion Portland cement concrete.

Sarker et al (2014) examined the effect of fire on fly ash geopolymer concrete. In a fire, the geopolymer concrete specimen had better resistance to spalling and cracking than the Ordinary Portland Cement (OPC) concrete specimen. Up to 650^{o}C, the geopolymer concrete specimens retained a larger percentage of strength than OPC concrete specimens. After being exposed to a high-temperature fire, the geopolymer microstructure remained stable and compact.

Jawahar et al (2016) studied the strength properties of geopolymer concrete made using Fly Ash (FA) and Ground Granulated Blast furnace Slag (GGBS). The findings of this study revealed that GGBS blended FA based GPC mixes achieved improved mechanical properties at room temperature without the need for heat curing, as compared to just FA based GPC mixes. At all ages, increasing the amount of GGBS in GPC mixes improved the mechanical characteristics at ambient room temperature curing.

Rao and Rao (2018) have used experimental approach to design the mix proportion of fly ash and GGBS-based geopolymer concrete. The level of substitution of fly ash with GGBS changed the requirement of oven curing to out-door curing, according to the test results. For all binder contents, the compressive strength values are maximum at an Alkaline-binder ratio of 0.5. The proposed mix design approach is applicable to both out-of-door and oven curing, and it aids in the design of GPC with compressive strengths ranging from 20 to 60 MPa.

Sreevidya and Ponkishan (2020) conducted the Strength evaluation of retrofitted geopolymer concrete using natural fibre. Geopolymer (GPC), GPC retrofitted without cracks, and GPC retrofitted with cracks **-** the experimental approach was used for all three groups. The evaluation of the studies found that the GPC retrofitted without cracks had a higher failure resistance and efficiency.

According to the study, geopolymer concrete based on FA-GGBS excelled geopolymer concrete based on FA in terms of strength with an alkaline binder ratio of 0.5. The geopolymer concrete performed better in a fire test than OPC concrete specimens.

2.5 EFFECT OF FIRE ON SLAB

Researchers have been studying the behaviour of reinforced concrete slabs under fire loading for decades. Structural fire performance engineering is a new design philosophy that has emerged in structural engineering recently. Active and passive fire protection systems can be used to improve fire safety design.

Allam et al (2013) evaluated the behaviour of one-way reinforced slabs exposed to fire in an experimental context. The steel reinforcement played a key impact in the slab's strength degradation, according to the observations. The fire resistance increased nearly linearly as the cover thickness was increased. The test result indicates that the maximum risk time was significantly affected by the thickness of the concrete cover and the presence of plaster. The maximum risk time values are almost unaffected by changes in the live load ratio.

Abass et al (2013) evaluated the retrofitting of reinforced concrete one-way damaged slabs exposed to high temperatures in an experiment conducted. The test results showed that adhering CFRP laminates to the tension face of RC slabs that had been burned and loaded till failure resulted in a considerable increase in flexural strength. Furthermore, at ultimate loads, the retrofitted slabs deflected more than the reference slabs. Concrete crushing prompted the majority of the tested slabs to fail at mid-span, and partial de-bonding of certain retrofitting systems was also observed.

Rousan (2020) investigated the Optimum fire endurance time of a reinforced concrete one-way slab subjected to fire. The test results show that by just replacing standard weight concrete with light weight concrete and keeping the same strength, it is feasible to increase the endurance time of an RC slab. The concrete strength had a substantial and diverse impact on the deflection at failure, but no effect on the failure time.

According to the research, when a structure is accidentally fired, the structural components crack, spall, and lose their bearing capacity. Furthermore, the fire resistance may be enhanced by increasing the concrete cover and by presence of plaster.

III. CONCLUSION

Following are the major conclusions derived from the literature study,

- Wrapping of FRP laminates on the soffit of slab provides higher strength than other wrapping configurations.
- Hybrid bonding techniques improved the strength of the structure significantly than conventional strengthening techniques.
- The geopolymer concrete outperformed ordinary Portland cement concrete in fire.
- The fibre thickness is crucial at high temperatures to avoid cracking and delamination of the fire protection layer and concrete cover.
- Increased FRP thickness at the bottom layer increases the performance of the RC slabs under impact loading.

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