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A Review on Fire Damaged Cement and Geopolymer Slabs Retrofitted with BFRP Laminates.

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ABSTRACT:
Fire is one of the most severe hazards which reinforced concrete (RC) buildings may be encountered during their service lives. Exposure of an RC Structure to high temperatures during a fire leads to material property degradations and concrete cracking, potentially resulting in significant losses in load bearing and deformation capacities of the associated structural members. Over the last few years, In the construction Industry, Fiber Reinforced Polymer (FRP) is commonly used for retrofitting. Various studies have been conducted on the use of FRP to reinforced fire-damaged cement and geopolymer concrete in order to improve the structural strength of the damaged structure. This study presents, several wrapping configurations, strengthening procedures, and different loading situations in different structural parts, as well as experimental, analytical and theoretical research.

KEY WORDS: *Retrofitting, Fire-Damaged cement, Wrapping Configuration, Strengthening*

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I. INTRODUCTION

Fire is one of the most dangerous threats that a structure can face over its lifetime. When a structure is damaged by fire, it is vital to determine the source of the fire and assess the structure's reusability. Retrofitting the damaged components of the structures, rather than dismantling it partially (or) totally, may be a superior approach in terms of economic efficiency. The first stage in reusing an old and damaged structure is to determine how much repair work is required, as well as how we might adapt or strengthen it. FRP laminates have recently been used to reinforce and retrofit damaged structural parts. Because, FRP has a number of distinct advantages including quick production and installation, high durability, light weight, resistance to corrosion, impact and fire. FRP can be utilized as sheets, mats, strips, laminates, reinforcing bars, or fibers combined with concrete. Carbon, glass, aramid, and basalt are examples of FRPs. These types have varying qualities depending on the composition; therefore, they can be utilized for different purposes.

II. LITERATURE REVIEW

The focus is on the use of Basalt Fiber Reinforced Polymer (BFRP) laminates to strengthen fire-damaged geopolymer reinforced concrete slabs. The behaviour of BFRP reinforced concrete elements, ductility, flexural capacity, and other parameters were studied using data collected from various journal papers in various approaches and aspects in order to fully utilised the effectiveness and properties of BFRP in the strengthening process.

2.1 EXPERIMENTAL INVESTIGATION ON STRUCTURAL ELEMENTS

Rapid deterioration of infrastructure is one of the major challenges facing the concrete industry around the world. The main cause of ageing, poor preservation, deterioration, construction errors, disruptive environmental health, poor basic design, and unforeseen conditions such as natural disasters is structural corrosion.

Huo et al (2013) concluded that the dynamic stress versus strain relations of fire-damaged concrete were clearly distinct from those of concrete at ambient temperature, according to test data. After exposure to high temperatures, there was no visible effect of temperature and strain rate on the form of the ascending branches of normalised stress–strain relation curves of concrete. High temperature and strain rate had a significant impact on the dynamic increase factor (DIF) for fire-damaged concrete, according to the research. As the temperature increased, the effect of high temperature on the DIF of the fire-damaged concrete dropped. The findings of the tests can be used to evaluate the impact and anti-collapse resistance of fire-damaged concrete structures.

Hemapriya and Meikandaan (2017) found that FRP retrofitted concrete structures have significantly increased in strength and stiffness. However, possible brittle failures of the retrofitted system may limit the usage of the FRP systems full efficiency. Premature debonding of the FRP, which could occur at load values much less than the strength of the FRP material used in the retrofitted system, is one of these brittle failures. As a result, a better understanding of the various failure modes of FRP reinforced concrete structures is required as the foundation for a reliable retrofit design.

Shen et al (2017) studies have focused on RC shear walls enhanced with FRP, research on RC shear walls strengthened with basalt FRP (BFRP) is restricted in comparison to RC shear walls strengthened with Carbon Fiber Reinforced Polymer (CFRP) or Glass Fiber Reinforced Polymer (GFRP). The failure modes, displacement ductility ratio, stiffness characteristic, energy dissipation capacity, and load carrying ability of six RC shear wall specimens with an aspect ratio of 1:6, described as medium-rise, were investigated using cyclic load. As a control, one of them was tested without any strengthening, while the other five were strengthened with BFRP strips of various configurations. In addition, the theoretical load carrying capability was estimated and compared to the test findings.

Nayak et al (2021) studied the flexural behaviour of RC T-beams is examined experimentally and analytically with BFRP. Results show that superficially bonded BFRP can greatly improve flexural capacity and reduce beam deflection. The data suggest that a 45-degree wrapping pattern was more successful than 90-degree wrapping and no wrapping. The RC T-beam was then modelled in ABAQUS to confirm the experimental and analytical results. The analytical results agree fairly with the experimental results after a series of comparison examinations.

Yuan et al (2021) the goal of this investigation is to see how effective epoxy anchors are at preventing IC debonding during three-point bending tests. The new epoxy anchors have the benefit of a simple installation technique that includes pre-drilling holes and then bonding FRP. Totally, five RC beams containing one control specimen and four anchored ones were tested. Damage modes, the consequences of different epoxy anchor configurations, and the structural behaviour of unanchored and anchored RC beams were all assessed and reviewed. The experimental results demonstrate that, as compared to the control specimen, the load-carrying capacity and ductility of anchored beams enhanced by up to 13.12% and 53.31%, respectively, and the strain utilisation of FRP improved by 43.48%.

According to the study, the FRP retrofitted concrete structures have greatly increased in strength and stiffness, according to the papers experimental and analytical observations. BFRP has a high flexural capacity and can reduce beam deflection significantly.

2.2 FIRE INSULATION

Fire is one of the most dangerous threats that a structure can face over its lifetime. When a structure is damaged by fire, it is vital to determine the source of the fire and assess the structures reusability.

Williams et al (2006) the results of an experimental and numerical study of the fire performance of unloaded, intermediate-scale, insulated FRP-strengthened RC slabs are presented in this paper. During exposure to the ASTM E119 standard fire, four slab specimens were reinforced and insulated, and their internal temperatures were recorded. Two distinct FRP strengthening systems were investigated, as well as three possible fire prevention schemes.

Gao et al (2016) found that the impact of concrete cover depth on RC beam fire resistance duration is highly dependent on the fire situation. The opening factor and thermal inertia of the enclosure's boundary have a big impact on the fire resistance period of RC beams, but the fuel load has no consequence. The combination of the energy-based time equivalence method and a correction factor provides a relatively reliable method for forecasting the fire resistance period of RC beams under design fire exposure.

This study concludes, provide the sufficient insulation thickness and it prevents the slab from cracking, spalling and delamination of the structural elements from fire.

2.3 GEOPOLYMER CONCRETE

Geopolymer Concrete (GPC) is a novel construction material that is made from inorganic molecules reacting chemically. It's a great alternative to the traditional plain cement concrete in construction.

Sarker et al (2014) studied that the specimens of fly ash based geopolymer and ordinary Portland cement (OPC) concrete cylinders were exposed to fires at temperatures ranging from 100 to 1000°C, with a heating rate equivalent with the International Standards Organization (ISO) 834 standard. The concretes showed compressive strengths ranging from 39 to 58 MPa. The geopolymer concrete specimens were found to have less cracking after being exposed to fire than the OPC concrete specimens. For 800 and 1000°C exposures, the OPC concrete cylinders exhibited extensive spalling, whereas the geopolymer concrete specimens did not. The strength of the geopolymer concrete specimens was generally higher than that of the OPC concrete specimens.

The difference in the thermal expansions of the geopolymer matrix and the aggregates caused the strength loss in the geopolymer concrete specimens.

Sreevidya and Ponkishan (2020) found that the sisal is a natural fibre with a high tensile strength and the ability to withstand failures. The wrapping of chicken mesh around the sisal fibre helps to achieve more strength and functions as an external reinforcing reinforcement. Sisal fibre and chicken are individually placed to the various members that are being tested without any resin impregnation. Concrete is significantly upgraded when it is contained with fibre ropes. Their resistance to failure demonstrates that they can be employed as retrofitting and strength reinforcing members in constructions. GPC retrofitted without cracks, and GPC retrofitted with cracks were all subjected to the experimental procedure. According to the findings, the GPC refitted without fractures has a higher failure resistance and efficiency.

Luhar et al (2021) investigated the degree of cracking, spalling, and loss of strength within geopolymer concretes after exposure to elevated temperatures, as well as the incidences of disastrous fires, provide evidence of their resilience to such seriously catastrophic conditions in the laboratory and in the field. The current analysis concludes that geopolymers are chemically stable at elevated temperatures, i.e., they do not undergo chemical structural breakdown, as seen in the case of the OPC hydration product. Thermal shrinkage or expansion occurs as a result of increased temperature exposure, which leads to macro cracking. Optimizing the amount of water in a geopolymer mix is crucial for regulating strength, spalling resistance, and thermal deformation.

The study reveals that Geopolymer concrete exhibits less cracking after being subjected to fire and has higher strength than OPC concrete specimens. At high temperatures, geopolymers are chemically stable and do not experience chemical structural breakdown.

2.4 FRP STRENGTHENING TECHNIQUE

Steel and cementitious materials are used in traditional strengthening techniques, although they do not provide the best options. Several composite technologies are currently in use for restoring and reinforcing RC structural members, and they may or may not be adequate. FRP laminates have recently been employed to strengthen and retrofit damaged structural parts. CFRP, GFRP, BFRP, and Aramid Fiber Reinforced Polymer (AFRP) are only a few examples of FRPs.

Williams et al (2004) investigated the heat transport properties of small-scale concrete slabs reinforced with FRP sheets and insulated with an innovative two-component fire prevention system. The slabs were exposed to a normal ASTME 119 fire and their overall performance was evaluated. Insulation thickness was previously identified as a critical parameter for the fire resistance of FRP-strengthened reinforced concrete elements. As a result, the thickness of the insulation was changed to test its capacity to sustain low temperatures at the FRP bond line, which are crucial for preventing FRP and insulation delamination. During fire exposure, a finite difference model was created to anticipate temperatures throughout the insulation, FRP, and concrete. In order to validate the model, model predictions were compared against test data. FRP-strengthened concrete slabs can provide adequate fire performance.

Chen et al (2008) conducted an experiment on a steel frame with four supporting surfaces, RC slab specimens were examined. Through a steel plate, they were centrally loaded with an MTS actuator. The capacity for strengthening and failure mode of slabs reinforced with various material systems were determined and compared. The failure process of slabs reinforced with various material systems was predicted using a finite element model created using the ANSYS programme. The expected and experimental outcomes are virtually identical.

Chen et al (2008) employed two design configurations of cross-shape and square-collar laminate to strengthen RC slabs. The square-collar laminate was far more effective in boosting load carrying capacity and preventing deflection at mid-length, according to experimental results. The cross-shape structure had no effect on the strength of reinforced concrete slabs in tests. This could be due to the laminate failing prematurely in the high-stress intersection area. The finite element model analysis of the designs correlated quite well with the experimental results. The analytical results also revealed an uneven distribution of stress levels in the cross-shape laminate, which could lead to early failure.

Huang (2010) made the initial step in this research to perform a detailed investigation of a uniformly loaded reinforced concrete slab that has been subjected to various degrees of concrete spalling under a conventional fire regime. A total of 16 examples were examined, each with varying degrees of slab spalling and variable sizes and locations of localised fire chambers. The surrounding cool structures clearly provide significant thermal restraint to the fire compartment's floor slabs. Furthermore, it is clear that the compressive membrane force within the slabs plays a key role in limiting the impact of concrete spalling on the structural behaviour of floor slabs in a fire.

Allam et al (2013) had the study goal to look at fire resistance and fire risk after a fire had been extinguished. The effect of essential parameters such as concrete cover thickness, plaster, and live load ratio on sixteen one-way reinforced concrete slabs was investigated. The fire resistance estimates were done using heat transfer through slab thickness equations. Even though the slabs were cooled before their fire resistance, the cooling time revealed that they are still prone to collapse. Furthermore, increasing the thickness of the concrete cover and the presence of plaster increased the maximum risk time. Variation in the live load ratio, on the other hand, has essentially little effect on this time.

Mote and Jadhav (2014) presented the results of an experimental research on the strengthening of RC short columns reinforced with BFRP wrap under axial loading. A total of fourteen reinforced concrete columns were cast and tested to failure under axial loading with the purpose of reinforcing them. BFRP sheets in single and double layers with varied configurations were used to bond the columns. Two of the fourteen columns were control columns, with the remaining columns reinforced with BFRP. The experimental results showed that BFRP-enhanced columns have a good load carrying capability and ductility index.

Raongjant and Jing (2016) used fiber reinforced polymer sheets as strengthening materials in this study. This article examined a new version of Fiber Reinforced Structural Insulated Panel (FSIP). Until failure, five one-way slabs were subjected to uniformly distributed loads. The thickness of the foam core and the strength of the FRP sheet were found to affect the slabs flexural bearing capacity and stiffness. The one-way slab of structural insulated panel can be utilised for floor and roof in residential and light commercial structures by strengthening it with FRP sheets.

Poorna and Prasad (2016) researched majorly on the percentage deflection of an RC slab when exposed to high temperatures. The behaviour of a slab at elevated temperatures with concrete grades M_{25}, M_{75}, and M_{100} with covers of 30mm, 40mm, and 50mm. The load-deflection pattern and percentage of deflection with and without heat were also investigated using a pressure of $0.1N/mm_2$. The effect of different grades of concrete with different covers was demonstrated using nine specimens. As the amount of cover given improves, the deflection of a slab reduces. It was also discovered that when the concrete grade increases, the slabs deflection reduces. The analysis revealed a minimal deflection for M_{100} with a cover of 50mm, according to the results obtained.

Shubhalakshmi et al (2017) used cross wrapping technique with mechanical anchoring to investigate the influence of BFRP on the flexural behaviour of slabs under static loads. After 28 days, control slabs were cast and evaluated under an evenly distributed loading condition. After 6 days of strengthening, the slabs were tested again, this time after they had been anchored. The initial fracture strength and ultimate load strength of retrofitted slabs with mechanical anchoring were found to improve by at least 39.585% and the stiffness of wrapped slabs was found to increase, according to the experimental results.

Kodur and Bhatt (2017) established the numerical model which employs a macroscopic finite element-based technique to track the thermo-mechanical response of FRP-strengthened RC slabs from linear elastic to collapse under fire conditions. The model takes into account temperature-dependent concrete, steel, FRP, and fire insulation properties, as well as temperature-induced bond breakdown between concrete and FRP. The results of the study show that an FRP-strengthened RC slab with no fire insulation has worse fire resistance than a regular RC slab. Furthermore, temperature-induced bond deterioration has a major impact on the fire performance of an FRP-strengthened RC slab, and failing to account for bond degradation may result in an overestimation of fire resistance.

Bhattacharyya et al (2019) investigated the influence of elevated temperature ranges on concrete, its contents, and the bond between the materials on a macro and micro level. Pores, micro cracks, and voids in concrete are the linkages that allow cracks to form. The concrete phase assembly is altered by non-uniform thermal expansion of components. The thermal expansion of standard and high-strength concrete with various mix amounts is investigated. Microscopic investigations look into the impact of concrete's porosity and chemical composition on its strength in the aftermath of a fire. In order to estimate the temperature exposure of structural parts in fire scenarios, microstructural changes in concrete at elevated temperatures are correlated with strength.

Sim et al (2005) assured that the basalt fiber was found to provide better resistance than the glass fiber. However, the basalt fiber kept about 90% of the normal temperature strength after exposure at 600°C for 2h whereas the carbon and the glass fibers did not maintain their volumetric integrity. In the tests for flexural strengthening evaluation, the basalt fiber strengthening improved both the yielding and the ultimate strength of the beam specimen up to 27% depending on the number of layers applied. From the results presented, two layers of the basalt fiber sheets were thought to be better strengthening scheme. In addition, the strengthening does not need to extend over the entire length of the flexural member. When moderate structural strengthening but high resistance for fire is simultaneously sought such as for building structures, the basalt fiber strengthening will be a good alternative methodology among other fiber reinforced polymer strengthening systems.

Fiore et al (2015) bonded BFRP with concrete with the help of epoxy resin. Basalt fibers were applied in two forms either fully or partially wrapping. Then all the tests were conducted in compression. And for comparison point of view few cylinders were wrapped with CFRP and tested in compression. The loading was also applied in two ways either monotonic or cyclic. 26 cylinders having cross section area of 150 x 300mm were casted. The compression tests were conducted after 7 and 28 days in UTM having a capacity of 5000KN and load was applied at a rate of 0.2mm/min and displacement was measured with the help of LVDTs, placed at an angle of 120°. This study shows that BFRP increases in confinement of RC specimens with a little increase in strain and also strain softening behavior exhibited.

Ma and Li (2017) presented the two levels of damaging i.e., damage at moderate level and severe damage to the R.C. columns by cyclic loading. While the retrofitting process, the displacement and axial load were kept constant. These specimens were tested again at room temperature after providing required epoxy and mortar curing. The energy and ductility dissipation capacities of retrofitted predamaged RC columns with fiber reinforced polymer were improved greatly after BFRP wrapping. The flexural strength of the moderate predamaged RC column was restored fully while it was partially restored for the severe predamaged columns.

Mohd Zahid et al (2018) reviewed existing repair materials and factors affecting their performance. Of the materials considered, ultra-high performance fiber reinforced concrete (UHPFRC) exhibits huge potential for repairing fire-damaged RC structures but lack of information available. Hence, further studies must be performed to assess the potential of UHPFRC in rehabilitating fire-damaged RC structures.

FRP-strengthened concrete slabs can provide adequate fire performance when using FRP-strengthening technology. The load carrying capacity of BFRP reinforced columns is excellent. Basalt fibre was discovered to be more resistant than glass fibre.

III. CONCLUSION

Following are the major conclusions derived from the literature study,

- Test results shows that the beams bonded with BFRP can greatly improve the flexural capacity and reduce beam deflection. Moreover, 45° wrapping pattern was more successful than 90° wrapping.
- The load carrying capacity and ductility of anchored beam are enhanced.
- Geopolymers are chemically stable at elevated temperatures and provides higher strength compared to OPC concrete specimens.
- The load carrying capacity of square collar laminate was far effective than cross shape Laminates.
- Double layers BFRP enhanced columns have a superior load carrying capacity and Ductility Index.
- Double layers of Basalt fiber sheets showed better strengthening effects.

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