REVISTAMATÉRIA
V.29 N.3
ISSN 1517-7076 articles e20240398, 2024

Enhancing fire resistance in reinforced concrete members through the application of hybrid fiber-reinforced polymers

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ABSTRACT

In this study, the reinforcement of reinforced concrete (RC) components with a combination of aramid and basalt fibers to enhance the overall structural performance and durability. In this empirical investigation, we meticulously assess the strength of concrete components both with and without the incorporation of fibers, while also scrutinizing the strengthening of concrete components exposed to the detrimental effects of fire. The concrete components under scrutiny encompass cubes, prism cylinders, and other specimens constructed from standard concrete, as well as concrete components enveloped with basalt fiber and aramid fiber. This research endeavor adopts the M20 mix for the concrete specimens, which are meticulously cast and cured in order to facilitate the subsequent testing of compressive strength (CS), flexural strength (FS), and split tensile strength (STS). The potency and fire-resistant properties of the standard concrete specimens are juxtaposed with those of the concrete specimens enveloped with basalt fiber and aramid fiber, which are then subjected to varying temperatures. Ultimately, the culmination of this project consists of the presentation of the findings and the comprehensive elucidation of the details derived from the aforementioned experiments.

Keywords: Aramid fiber; Basalt fiber; Reinforced concrete.

1. INTRODUCTION

The strengthening of RC structures using fibers is commonly referred to as fiber-reinforced concrete (FRC). Fibers are added to the concrete mix to enhance various mechanical properties and improve the structural performance of the material. Different types of fibers, such as steel, glass, synthetic, and natural fibers, can be used for this purpose. The primary focus of the research work [1] is to examine the fire resistance of wood fiber reinforced concrete and its potential as a viable alternative for building materials. The authors have devised and implemented two distinct testing apparatuses to assess the behavior of the material under high-temperature conditions. These include 4-point bending TS tests and flame exposure trials. The study undertakes a comparative analysis of the fire resistance capabilities of wood fiber-reinforced concrete in comparison to a reference concrete. This analysis involves evaluating the flexural strength and surface TS measurements. The findings of this study indicate that the wood fiber-reinforced specimens did not exhibit any decline in strength when subjected to flame exposure. In contrast, the reference concrete experienced a 10% decrease in strength. The main objective of this research endeavor is to enhance our comprehension of the fire resistance properties associated with this innovative form of concrete construction, as well as to determine the impact of wood fibers on its overall performance. The research work [2] investigates the use of hybrid sandwich panels in building applications, with a specific focus on the interface between glass fiber-reinforced polymer (GFRP) and mineral matrix. The researchers aimed to explore the properties and performance of these hybrid sandwich panels, which combine GFRP and mineral materials, and their potential for use in the construction industry. The researchers focused on the interface between GFRP and the mineral matrix. Various tests and analyses were conducted to evaluate the mechanical properties, bond strength, and durability of the hybrid panels. The research also involved examining the behavior of the panels under different loading conditions. The findings shed light on the potential advantages and limitations of using hybrid sandwich panels in building applications. The interface between GFRP and the mineral matrix was found to play a crucial role in the mechanical behavior of the panels. The authors discussed the potential applications and benefits of these hybrid panels in terms of lightweight construction, energy efficiency, and sustainable building practices.

Corresponding Author: Charles Dyson Received on 01/07/2024 Accepted on 08/08/2024

DOI: https://doi.org/10.1590/1517-7076-RMAT-2024-0398

The effect of fiber wrapping on the bending behavior of reinforced concrete-filled pultruded glass fiber-reinforced polymer (GFRP) composite hybrid beams was put forward in this research [3]. The researchers aimed to evaluate the mechanical performance and behavior of these hybrid beams with different fiber wrapping configurations under bending loads. Reinforced concrete-filled pultruded GFRP composite beams were manufactured with various fiber wrapping configurations. These configurations included different orientations and layering patterns of fibers around the beams. The beams were then subjected to bending tests to evaluate their load-carrying capacity, stiffness, and failure modes. Finite element analysis was also performed to further understand the behavior of the hybrid beams. The fiber wrapping has a significant effect on the bending behavior of reinforced concrete-filled pultruded GFRP composite hybrid beams. A comprehensive review of the repair techniques used for fire-damaged reinforced concrete members that are subjected to axial loads was proposed in [4]. The authors delve into the challenges faced when repairing concrete structures that have been exposed to high temperatures during a fire event, particularly when these structures also experience axial load effects. It provides insights into the performance and effectiveness of different repair techniques, highlighting their advantages, limitations, and applicability.

A comprehensive review of the state-of-the-art research on the blast resistance of structures reinforced with Fiber-Reinforced Polymer (FRP) composites and polymer-strengthened concrete and masonry was proposed in [5]. The authors examine the application of these materials and techniques to enhance the blast resistance of structures, considering their effectiveness and limitations. The authors discuss the behavior of FRP composites and polymer-strengthened materials under blast loading conditions, including their ability to enhance the structural response and mitigate damage. They explore the effects of different factors, such as material properties, reinforcement configurations, and retrofit techniques, on the blast resistance of concrete and masonry structures. In [6], the author investigates the shear strength of RC columns that have been retrofitted using glass fiber reinforced polyurea (GFRP). The authors aim to assess the effectiveness of GFRP as a retrofitting material for improving the shear capacity of concrete columns. The experimental program involves applying GFRP sheets or strips to the columns and subjecting them to shear loading. The authors measure and analyze various parameters, such as load-displacement behavior, shear strength, failure modes, and ductility, to evaluate the proficiency of GFRP retrofitting.

The main focus of the research work [7] is to investigate the properties and material models of construction materials after being exposed to elevated temperatures. The authors aim to understand the behavior and characteristics of construction materials, such as concrete, steel, and composite materials, after being subjected to high temperatures. The paper addresses the significance of studying the post-fire behavior of construction materials, as fires can significantly affect their mechanical properties and structural performance. The authors review and analyze existing research to identify the changes in material properties caused by exposure to elevated temperatures. The research work [8] investigate the flexural behavior of timber beams that have been strengthened using pultruded glass fiber reinforced polymer (GFRP) profiles. The authors aim to evaluate the effectiveness of GFRP strengthening in enhancing the load-carrying capacity and stiffness of timber beams under flexural loading. The findings of the study provide insights into the flexural behavior and strength enhancement of timber beams strengthened with pultruded GFRP profiles. The authors discuss the influence of different strengthening configurations, such as the number and orientation of GFRP profiles, on the performance of the beams. In [9], the authors discussed the strengthening of reinforced concrete using fiber reinforced polymer composites. The review highlights the strengthening and retrofitting methods utilizing fiber reinforced polymer composites. A review of various composite systems used for the strengthening of reinforced concrete (RC) slabs. The authors [10] aim to summarize and analyze different composite materials and techniques employed to enhance the load-carrying capacity and performance of RC slabs.

The study [11] examines the employment of basalt fiber reinforced polymer (BFRP) textiles in order to enhance the rigidity of reinforced concrete (RC) compression elements, leading to an augmentation in the load capacity, shear capacity, and ductility of concrete columns. BFRP fabrics are economically efficient, exhibit a greater fracture strain, and possess a higher level of durability compared to alternative fiber reinforced polymer (FRP) materials, thus rendering them a suitable preference for the reinforcement of RC structures. The research [12] examines the possibility of enhancing the strength of Tin Slag Polymer Concrete (TSPC) by means of confinement employing basalt fiber reinforced polymer (BFRP) and aramid fiber reinforced polymer (AFRP) confinement. Basalt fiber sheets [13] were investigated as a shear strengthening material for reinforced concrete (RC) beams, with experimental outcomes showing an increase in failure load by 17–50% and an enhancement in toughness up to 2.74 times compared to the reference specimen. The study [14] emphasizes the assessment of the performance of beam column joints made of reinforced concrete, which exhibit susceptibility to failure in the event of seismic activity. Furthermore, it puts forth a suggestion to employ aramid fiber as a means of retrofitting in order to augment the strength and ductility of said joints. Basalt and polypropylene fibers [15] are economically viable and resistant to corrosion materials that possess the ability to augment the shear strength of reinforced concrete (RC) beams. There has been limited exploration into the shear conduct of RC beams fabricated with these fibers. The objective of this investigation is to scrutinize the shear behavior of RC beams fabricated with basalt and polypropylene fibers and ascertain the most advantageous percentage of each fiber. A total of eight RC beams were subjected to testing with varying proportions of basalt and polypropylene fibers. Section 2 highlights the materials and methods followed by experimental results and discussion in section 3 and section 4 put forwards the conclusion.

The research [16] focuses on the retrofitting of fire damaged cement and geopolymer concrete structural elements with BFRP wraps. The slab specimens were exposed to a temperature of 200, 400, 600 and 800°C for 1, 2 and 3 hours. The damaged specimens were then retrofitted with BFRP. The Basalt FRP retrofitted slabs ultimate load carrying capacity increased by 80%. The study [17] focuses on numerical simulation of Carbon FRP and Glass FRP reinforced concrete specimen to forecast its stress-strain behaviour. The validation of the numerical modelling was confirmed with the already published results. The study aims to [18] examine the behaviour of laminated Carbon and Glass Fiber reinforced polymer and to find the optimal configuration for the reinforcement and can be used as material for rehabilitation and repair of old buildings.

2. MATERIALS AND METHODS

Basalt fiber is recognized for its ability to withstand fire, resist corrosion, and provide a cost-effective solution, rendering it applicable across diverse uses. On the other hand, Aramid fiber, represented by materials like Kevlar, stands out for its impressive tensile strength, lightweight nature, and outstanding resistance to flames, making it especially well-suited for advanced applications in aerospace and protective equipment. This research work employs a hybrid combination of basalt and aramid fiber for the strengthening of reinforced concrete elements. For this research work, the following are the standards adopted; grade of concrete adopted is M20, nominal size of aggregate used is 20 mm, shape of coarse aggregate is angular, water cement ratio is 0.48, workability of the concrete is 75 mm (slump), specific gravity of cement is 3.15, specific gravity of fine aggregate is 2.69, specific gravity of coarse aggregate is 2.75, type of cement used is Portland Pozzolana Cement The mix proportion of concrete is found out by doing mix design referring to code IS 10262 : 2019. From the mix design the quantity of cement, fine aggregate and coarse aggregate required per m3 is known. Hybrid FRPs wrapping over reinforced concrete members enhances its fire resistance. The Fibers protects the reinforced concrete members offering extra shield, thus slowing down its deterioration when subjected to high temperatures. This extends the duration before the reinforcement within the concrete becomes vulnerable to fire exposure, ultimately improving the structure's overall fire resilience.

2.1. Casting

Specimens were fabricated using M_{20} grade concrete, following the mix proportions determined through mix design. The quantities of materials used for casting the specimens were obtained from the mix design, resulting in 365 kg/m^3 of cement, 597 kg/m^3 of fine aggregate, and 1154 kg/m^3 of coarse aggregate. The specimens were cast in the form of cubes, cylinders, and prisms using moulds. The cubic specimens had dimensions of 15 cm × 15 cm × 15 cm, the cylindrical specimens had a diameter of 15 cm and a height of 30 cm, and the prism specimens measured 10 cm × 10 cm × 50 cm. Both cast-iron and wooden moulds were utilized for moulding the cubes, cylinders, and prisms.

2.2. Curing

Curing is a vital process that involves maintaining the concrete moist for a specific duration, allowing it to develop increased strength. During this process, the concrete specimens absorb the necessary water to facilitate the completion of chemical reactions required for achieving the desired strength. After the demolding, the specimens are subjected to a curing period of 28 days immersed in water. Various methods can be employed for concrete curing, and in our project, we utilize the ponding method. In the ponding method, the entire surface area of the specimens is divided into smaller square or rectangular blocks. These blocks are then filled with water, creating small ponds that cover the entire surface area. Once the 28-day curing period is complete, the specimens are removed from the water, allowing for further testing to be conducted.

2.3. Wrapping of basalt fiber

Wrapping basalt fiber around reinforced concrete (RC) elements is a common practice to strengthen existing structures. Derived from basalt rock, this fiber is chosen for its notable tensile strength, resistance to corrosion, and fire resistance. The overall process is shown as flow diagram in Figure 1.

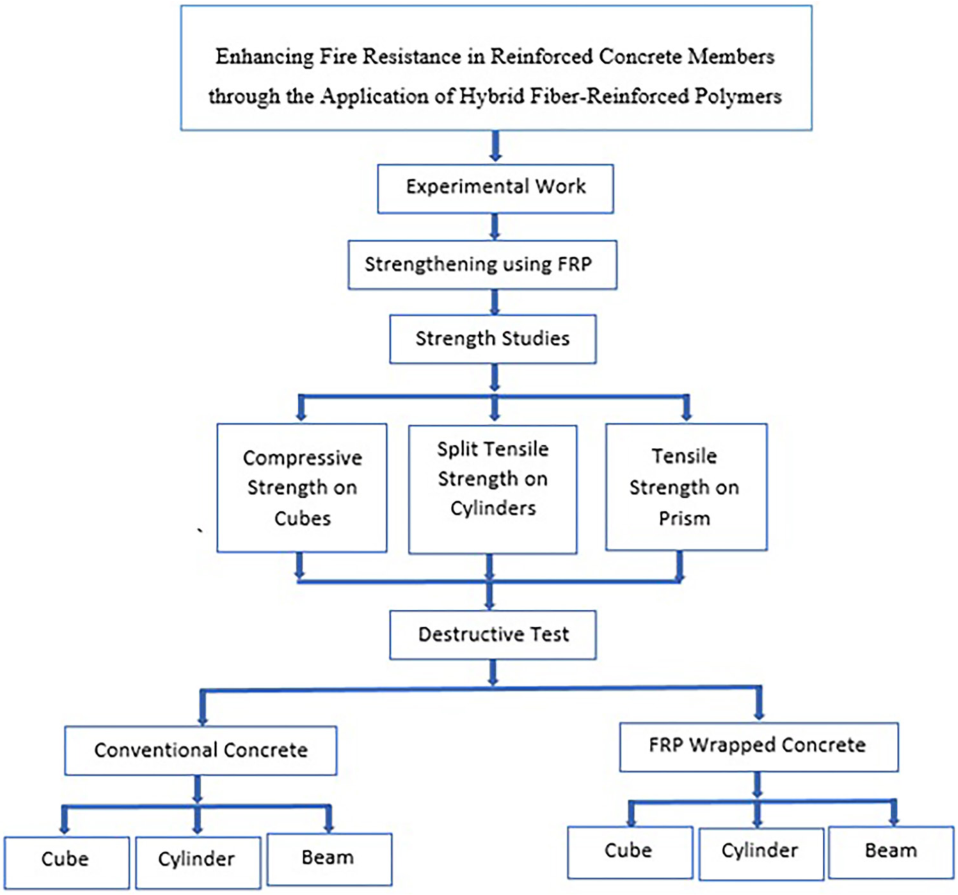

Figure 1: Overall flow diagram of the process.

- Examine the RC elements thoroughly to identify areas of damage or insufficient load capacity.
- Analyze the structural requirements based on factors like damage extent, loading conditions, and desired improvement.
- Choose appropriate basalt fiber sheets or fabrics based on the application's needs.
- Clean the RC element surfaces, removing contaminants and ensuring a sound substrate.
- Apply a compatible epoxy or cementitious adhesive to serve as the bonding agent.
- Wrap the basalt fiber sheets around the RC element, ensuring proper alignment and coverage.
- Ensure full saturation of basalt fiber with the adhesive for a strong bond.
- Apply additional layers based on design requirements.
- Allow the strengthened elements to cure under recommended conditions.
- Implement quality control processes, including non-destructive or destructive testing.
- Confirm that the wrapped elements meet fire safety requirements.

2.4. Wrapping of aramid fiber

To further enhance the rehabilitation, and structural strengthening of old or weakened RCC structural members, aramid fiber wrapping is applied over the previously applied basalt fiber wrapping. Aramid fibers are preferred for their lightweight characteristics and availability in various lengths, making them widely utilized for strengthening purposes. The aramid fiber wrapping significantly improves the strength and ductility of the concrete structure. The aramid fibers are cut into strips and applied over the basalt fiber wrapping in a horizontal direction. The adhesive used for wrapping the aramid fiber to the basalt fiber is epoxy resin (LY556) combined with Hardener (HY951). The recommended ratio for this adhesive mixture is 1 kg of resin to 300 ml of hardener. Similar stages in the wrapping of Basalt fiber are adopted here.

2.5. Strengthening validation

The 28-day cured concrete cubes and cylinders are subjected to fire exposure inside a furnace. The specimens are carefully exposed to temperatures of 250°C and 500°C for a duration of 1, 2 and 3 hours. The temperature levels are controlled using a temperature sensor that accurately measures the temperature inside the furnace. Once the exposure time is complete, the specimens are removed from the furnace and allowed to cool down to room temperature. The initial testing involves assessing the strength of some of these specimens. The compressive strength of the cube specimens is measured using a compressive strength testing machine. The split tensile strength of the cylindrical specimens is evaluated using a tensile strength testing machine. Furthermore, the flexural strength of the prism specimens is determined using a double point load flexural testing machine. Based on these tests, the results are obtained.

After 24 hours, a portion of the fire-exposed specimens is cleaned, and basalt fiber is uniaxially wrapped around all four sides of the specimens using a mixture of epoxy resin and hardener. Aramid fiber strips are then applied horizontally over the basalt fiber wrapping. The wrapped specimens are left to dry for 7 days. Once the drying period is complete, the strength of the fiber-wrapped specimens is tested. The CS of the cube specimens wrapped with fiber is assessed using a compressive strength testing machine. The STS of the cylindrical specimens wrapped with fiber is tested using a TS testing machine. Similarly, the FS of the prism specimens wrapped with fiber is determined using a flexural testing machine. Finally, a comparison is made between the strength of the specimens wrapped with basalt and aramid fiber and those without any fiber wrapping.

The Fibers retards the transfer of heat into the concrete. Thus, hybrid FRP wrappings protects and delays the deformation of concrete from heat generated by fire. This delay in concrete heating helps to maintain its mechanical properties for an extended period under fire exposure. Till date there is there is no Indian Standard Codal provisions for the use of hybrid FRP wrappings for fire resistant structures and only a little information about its use is available. The FRP is resistant to corrosion and chemical attack it can be used in harsh environment for construction and to delay the damage caused by fire.

3. RESULTS AND DISCUSSION

The fibers are wrapped on the specimen in four different ways; aramid fiber alone is wrapped, basalt fiber alone is wrapped, aramid fiber is wound first followed by basalt fiber, basalt fiber is wound first followed by aramid fiber. The test is carried out in the samples concerning the above conditions as well as the sample without wrapping. The CS of concrete, whether in a standard mix or a sample reinforced with fibers, denotes the concrete's capacity to resist axial forces or pressures that bring the material closer together. The inclusion of fibers in the concrete mix or their application around the sample is typically undertaken to improve specific characteristics like tensile strength, ductility, and resistance to cracking.

The ability of materials, commonly concrete or other construction materials, to resist compressive forces under heightened temperatures characterizes the compressive strength of specimens at elevated temperature. The results in Table 1, shows that the fiber wrapped specimens withstands elevated temperature compared to conventional concrete for compressive strength at 250° for 1, 2 & 3 hours.

Here in the above graph shown in Figure 2, the following are the specifications

Case 1: Conventional Concrete (Without fiber)

Case 2: Wrapped sample (Basalt)

Case 3: Wrapped sample (Aramid)

Case 4: Wrapped sample (Basalt + Aramid)

Case 5: Wrapped sample (Aramid + Basalt) N/mm^2

R1: Compressive Strength for Conventional concrete

R2: Compressive Strength after heating at 250°C for 1 hour

R3: Compressive Strength after heating at 250°C for 2 hours

R4: Compressive Strength after heating at 250°C for 3 hours

This examination is essential for evaluating how materials maintain their structural performance and integrity when exposed to elevated temperatures, as seen in scenarios like fire or high-temperature environments.

The results in Table 2, shows that the fiber wrapped specimens withstands elevated temperature compared to conventional concrete for compressive strength at 500° for 1, 2 & 3 hours.

Here in the above graph shown in Figure 3, the following are the specifications

Table 1: Compressive strength of conventional concrete and fiber wrapped concrete at 250°C for 1, 2 & 3 hours.

TEMPERATURE /DURATION	SPECIMEN ID	COMPRESSIVE STRENGTH (N/mm²)				
		WITHOUT WRAPPING	WRAPPED SAMPLE (BASALT)	WRAPPED SAMPLE (ARAMID)	WRAPPED SAMPLE (BASALT + ARAMID)	WRAPPED SAMPLE (ARAMID + BASALT)
Room Temperature	CC20-01	20.55	21.93	21.89	22.10	22.08
	CC20-02	21.33	21.82	22.01	22.39	22.07
	CC20-03	21.15	21.88	21.97	22.32	22.10
250°C for 1 hour	CC20-04	19.32	20.71	20.80	21.12	21.13
	CC20-05	19.97	20.33	20.92	21.10	21.72
	CC20-06	20.03	19.98	21.01	21.41	21.65
250°C for 2 hours	CC20-07	17.11	18.92	18.71	20.77	20.60
	CC20-08	17.43	18.23	19.63	20.91	20.61
	CC20-09	16.41	18.56	18.90	20.09	20.53
250°C for 3 hours	CC20-10	13.21	16.66	16.70	18.88	19.04
	CC20-11	14.12	17.19	16.98	18.91	18.51
	CC20-12	14.55	16.03	17.71	18.31	18.09

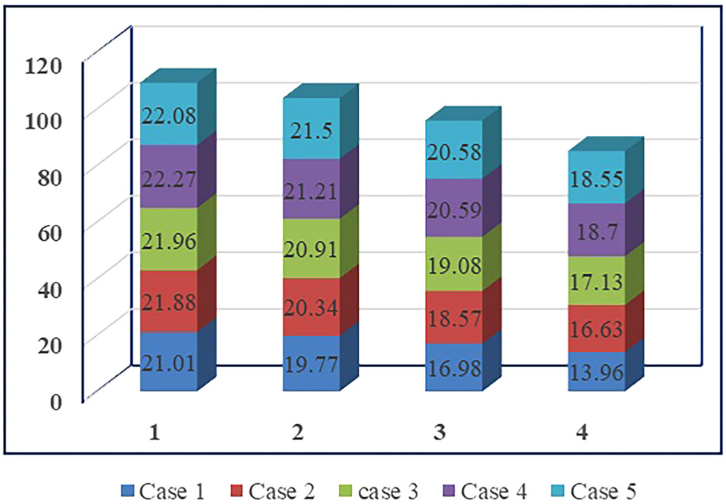

Figure 2: Average compressive strength of conventional concrete and fibre wrapped concrete at 250°C for 1, 2 & 3 hours.

Case 1: Conventional Concrete (Without fiber)
Case 2: Wrapped sample (Basalt)
Case 3: Wrapped sample (Aramid)
Case 4: Wrapped sample (Basalt + Aramid)
Case 5: Wrapped sample (Aramid + Basalt)
R1: Compressive Strength for Conventional concrete
R2: Compressive Strength after heating at 500°C for 1 hour
R3: Compressive Strength after heating at 500°C for 2 hours
R4: Compressive Strength after heating at 500°C for 3 hours

The split tensile strength of both nominal mix and fiber-wrapped samples pertains to concrete's resistance against forces causing splitting, where tensile stresses operate perpendicular to the applied load. The introduction of fibers into the concrete mix or their application around the sample is typically undertaken to improve characteristics such as tensile strength, ductility, and overall resilience. The assessment of split tensile strength offers valuable information about the material's capacity to endure tensile stresses and mitigate the risk of potential cracking.

Table 2: Compressive strength of conventional concrete and fiber wrapped concrete at 500°C for 1, 2 &3 hours.

TEMPERATURE /DURATION	SPECIMEN ID	COMPRESSIVE STRENGTH (N/mm²)				
		WITHOUT WRAPPING	WRAPPED SAMPLE (BASALT)	WRAPPED SAMPLE (ARAMID)	WRAPPED SAMPLE (BASALT + ARAMID)	WRAPPED SAMPLE (ARAMID + BASALT)
Room Temperature	CC20-01	20.55	21.93	21.89	22.10	22.08
	CC20-02	21.33	21.82	22.01	22.39	22.07
	CC20-03	21.15	21.88	21.97	22.32	22.10
500°C for 1 hour	CC20-16	17.21	19.91	19.92	20.87	20.91
	CC20-17	17.71	19.97	19.79	20.79	21.02
	CC20-18	17.46	19.87	19.91	20.79	20.53
500°C for 2 hours	CC20-19	15.92	17.76	17.59	18.54	19.11
	CC20-20	15.97	17.87	17.53	19.61	18.19
	CC20-21	16.59	18.51	17.90	18.62	18.92
500°C for 3 hours	CC20-22	12.56	16.13	16.81	16.99	17.11
	CC20-23	13.59	16.29	16.99	17.56	17.19
	CC20-24	12.71	16.81	15.85	17.55	17.58

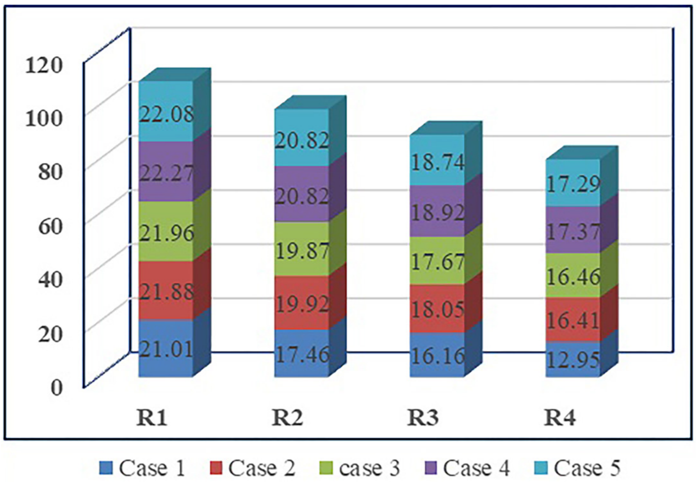

Figure 3: Average compressive strength of conventional concrete and fibre wrapped concrete at 500°C for 1, 2 & 3 hours.

The results in Table 3, shows that the fiber wrapped specimens withstands elevated temperature compared to conventional concrete for 250° for 1, 2 & 3 hours for the split tensile test.

Here in the above graph shown in Figure 4, the following are the specifications

Case 1: Conventional Concrete (Without fiber)
Case 2: Wrapped sample (Basalt)
Case 3: Wrapped sample (Aramid)
Case 4: Wrapped sample (Basalt + Aramid)
Case 5: Wrapped sample (Aramid + Basalt)
R1: Split tensile Strength for Conventional concrete
R2: Split tensile Strength after heating at 250° C for 1 hour
R3: Split tensile Strength after heating at 250° C for 2 hours
R4: Split tensile Strength after heating at 250° C for 3 hours

The results in Table 4, shows that the fiber wrapped specimens withstands elevated temperature compared to conventional concrete for 500° for 1, 2 & 3 hours for the split tensile test.

Table 3: Split tensile strength of conventional concrete and fiber wrapped concrete at 250°C for 1, 2 & 3 hours.

TEMPERATURE /DURATION	SPECIMEN ID	SPLIT TENSILE STRENGTH (N/mm²)				
		WITHOUT WRAPPING	WRAPPED SAMPLE (BASALT)	WRAPPED SAMPLE (ARAMID)	WRAPPED SAMPLE (BASALT + ARAMID)	WRAPPED SAMPLE (ARAMID + BASALT)
Room Temperature	CS20-01	2.78	3.12	3.27	4.01	4.04
	CS20-02	2.72	3.22	3.28	4.22	4.01
	CS20-03	2.81	3.29	3.30	4.19	3.95
250°C for 1 hour	CS20-04	2.02	3.01	2.91	3.11	3.70
	CS20-05	2.10	2.50	2.87	3.19	3.68
	CS20-06	1.98	2.43	2.82	3.21	3.33
250°C for 2 hours	CS20-07	1.68	2.59	1.90	2.87	2.91
	CS20-08	1.16	2.71	1.91	2.86	2.88
	CS20-09	1.53	2.43	1.96	2.73	2.83
250°C for 3 hours	CS20-10	0.75	1.76	1.11	1.97	1.95
	CS20-11	1.00	1.19	1.23	2.10	1.97
	CS20-12	1.02	1.26	1.27	2.03	2.00

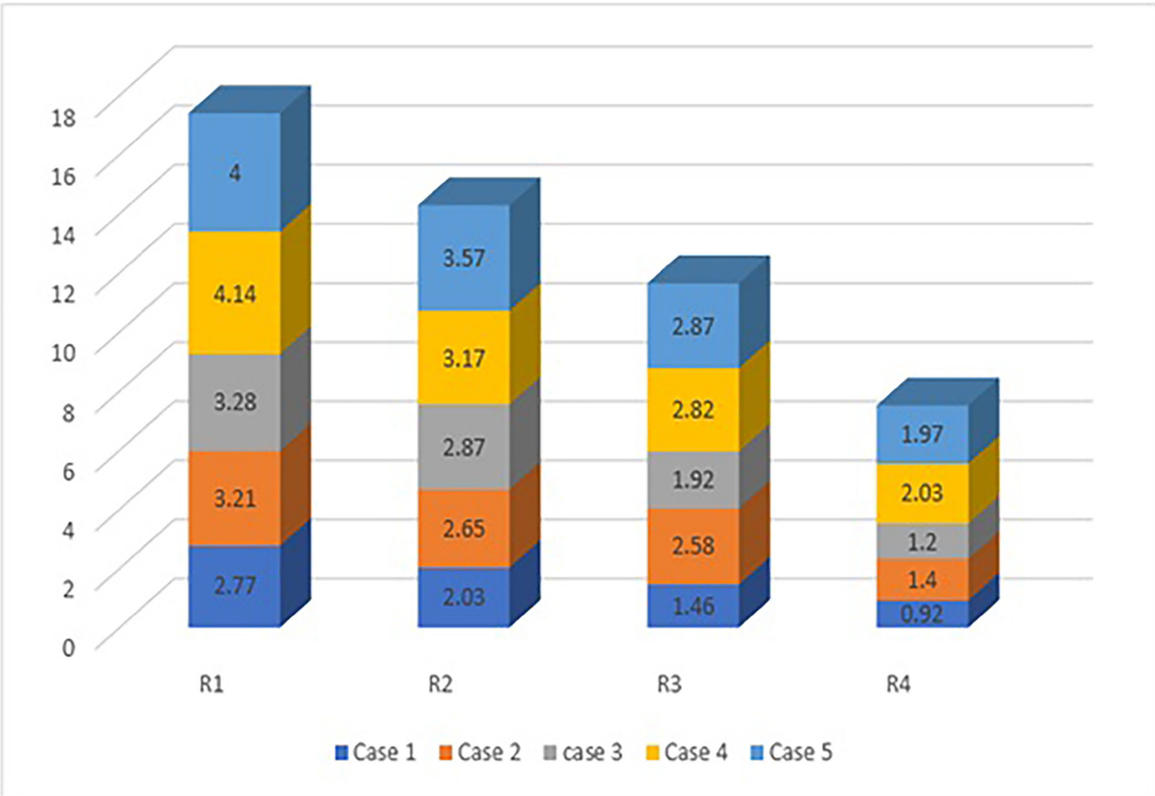

Figure 4: Average split tensile strength of conventional concrete and fiber wrapped concrete at 250°C for 1, 2 & 3 hours.

Here in the above graph shown in Figure 5, the following are the specifications

Case 1: Conventional Concrete (Without fiber)

Case 2: Wrapped sample (Basalt)

Case 3: Wrapped sample (Aramid)

Case 4: Wrapped sample (Basalt + Aramid)

Table 4: Split tensile strength of conventional concrete and fiber wrapped concrete at 500°C for 1, 2 & 3 hours.

TEMPERATURE /DURATION	SPECIMEN ID	SPLIT TENSILE STRENGTH (N/mm²)				
		WITHOUT WRAPPING	WRAPPED SAMPLE (BASALT)	WRAPPED SAMPLE (ARAMID)	WRAPPED SAMPLE (BASALT + ARAMID)	WRAPPED SAMPLE (ARAMID + BASALT)
Room Temperature	CS20-01	2.78	3.12	3.27	4.01	4.04
	CS20-02	2.72	3.22	3.28	4.22	4.01
	CS20-03	2.81	3.29	3.30	4.19	3.95
500°C for 1 hour	CS20-16	1.61	2.41	1.98	2.12	2.45
	CS20-17	1.09	2.62	1.83	2.22	2.45
	CS20-18	1.51	2.1	1.88	2.29	2.52
500°C for 2 hours	CS20-19	0.91	1.10	1.33	2.06	1.76
	CS20-20	0.98	1.06	1.01	1.98	1.79
	CS20-21	0.89	1.12	1.03	1.81	1.83
500°C for 3 hours	CS20-22	0.59	0.91	0.98	1.75	1.10
	CS20-23	0.51	0.78	0.98	1.81	1.19
	CS20-24	0.62	0.79	1.10	1.64	1.39

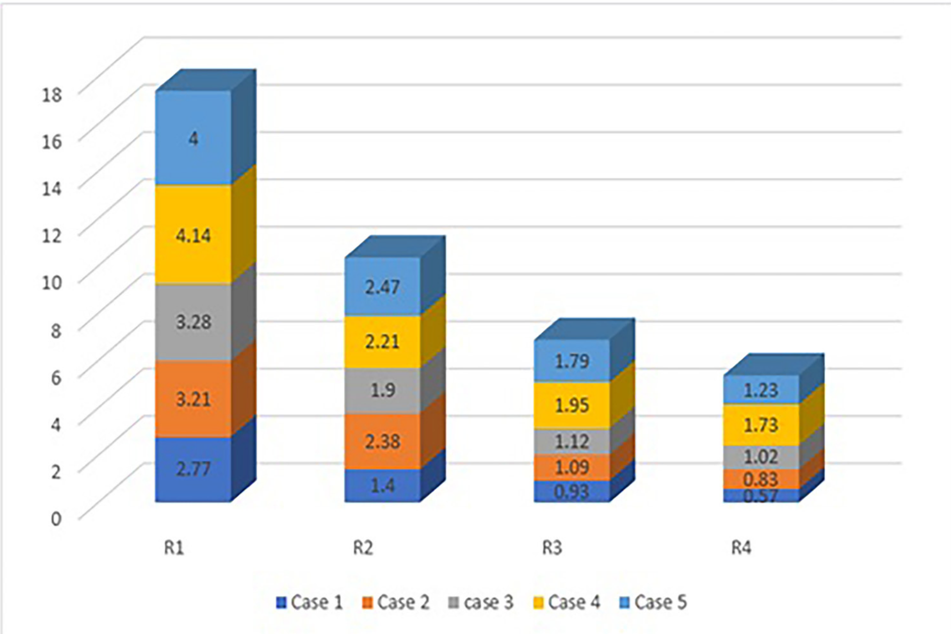

Figure 5: Average split tensile strength of conventional concrete and fiber wrapped concrete at 500°C for 1, 2 & 3 hours.

Case 5: Wrapped sample (Aramid + Basalt)
R1: Split tensile Strength for Conventional concrete
R2: Split tensile Strength after heating at 500° C for 1 hour
R3: Split tensile Strength after heating at 500° C for 2 hours
R4: Split tensile Strength after heating at 500° C for 3 hours

The capacity of concrete to withstand forces that seek to pull the material apart defines the tensile strength of prisms, whether in nominal mix or fiber-wrapped samples. This testing is crucial for evaluating how the material performs under tension, and the addition of fibers is frequently employed to improve not only tensile strength but also enhance ductility and overall durability.

Table 5: Tensile strength of conventional concrete and fiber wrapped concrete at 250°C for 1, 2 & 3 hours.

TEMPERATURE /DURATION	SPECIMEN ID	TENSILE STRENGTH (N/mm²)				
		WITHOUT WRAPPING	WRAPPED SAMPLE (BASALT)	WRAPPED SAMPLE (ARAMID)	WRAPPED SAMPLE (BASALT + ARAMID)	WRAPPED SAMPLE (ARAMID + BASALT)
Room Temperature	CT20-01	4.70	4.99	5.06	5.59	5.61
	CT20-02	4.82	4.91	5.07	5.97	5.34
	CT20-03	4.13	5.02	5.10	5.91	5.42
250°C for 1 hour	CT20-04	4.10	4.51	4.45	5.13	4.91
	CT20-05	3.99	4.45	4.76	4.97	4.97
	CT20-06	3.91	4.11	4.78	4.98	4.86
250°C for 2 hours	CT20-07	3.19	4.01	4.11	4.45	4.30
	CT20-08	2.95	3.98	4.12	4.51	4.41
	CT20-09	2.93	3.92	4.03	4.61	4.39
250°C for 3 hours	CT20-10	2.91	2.56	3.23	3.99	3.75
	CT20-11	2.12	3.51	3.76	4.03	3.79
	CT20-12	2.97	3.13	2.90	3.89	3.61

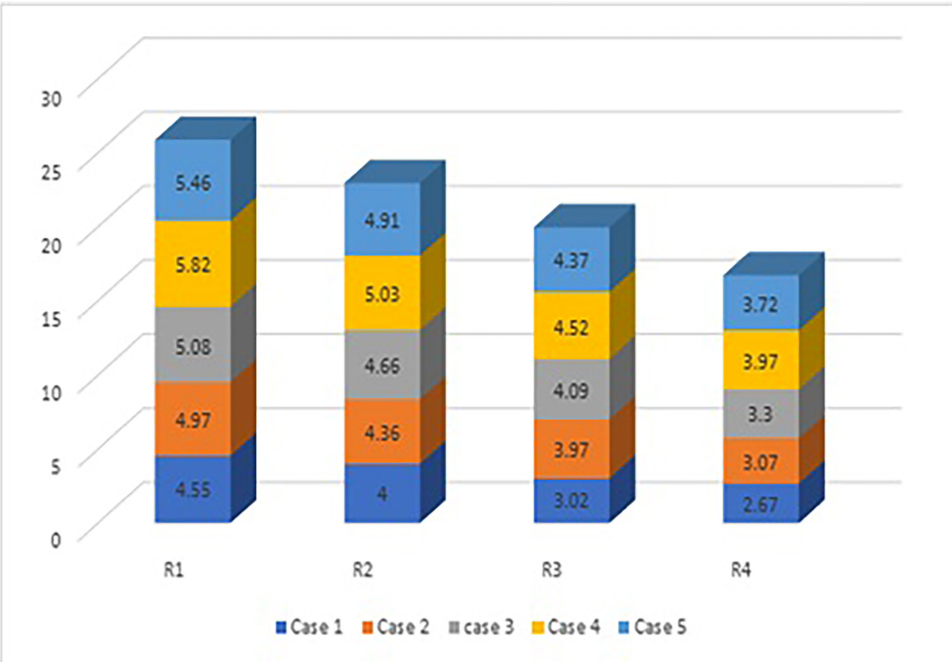

Figure 6: Average tensile strength of conventional concrete and fiber wrapped concrete at 250°C for 1, 2 & 3 hours.

The results in Table 5, shows that the fiber wrapped specimens withstands elevated temperature compared to conventional concrete for 250° for 1, 2 & 3 hours for the tensile test.

Here in the above graph shown in Figure 6, the following are the specifications

Case 1: Conventional Concrete (Without fiber) N/mm²

Case 2: Wrapped sample (Basalt) N/mm²

Case 3: Wrapped sample (Aramid) N/mm²

Case 4: Wrapped sample (Basalt + Aramid) N/mm²

Case 5: Wrapped sample (Aramid + Basalt) N/mm²

R1: Tensile strength (N/mm²) for conventional concrete

Table 6: Tensile strength of conventional concrete and fiber wrapped concrete at 500°C for 1, 2 & 3 hours.

TEMPERATURE /DURATION	SPECIMEN ID	TENSILE STRENGTH (N/mm²)				
		WITHOUT WRAPPING	WRAPPED SAMPLE (BASALT)	WRAPPED SAMPLE (ARAMID)	WRAPPED SAMPLE (BASALT + ARAMID)	WRAPPED SAMPLE (ARAMID + BASALT)
Room Temperature	CT20-01	2.78	3.12	3.27	4.01	4.04
	CT20-02	2.72	3.22	3.28	4.22	4.01
	CT20-03	2.81	3.29	3.30	4.19	3.95
500°C for 1 hour	CT20-16	3.01	3.99	4.03	4.79	4.41
	CT20-17	2.90	3.87	4.02	4.66	4.32
	CT20-18	3.12	3.93	3.94	4.81	4.67
500°C for 2 hours	CT20-19	1.91	2.93	3.30	3.71	3.59
	CT20-20	1.93	2.97	2.93	3.61	3.13
	CT20-21	2.09	3.01	3.09	3.93	3.22
500°C for 3 hours	CT20-22	1.86	1.99	2.11	2.95	2.73
	CT20-23	1.39	2.03	2.33	2.88	2.81
	CT20-24	1.10	1.97	1.82	3.12	2.90

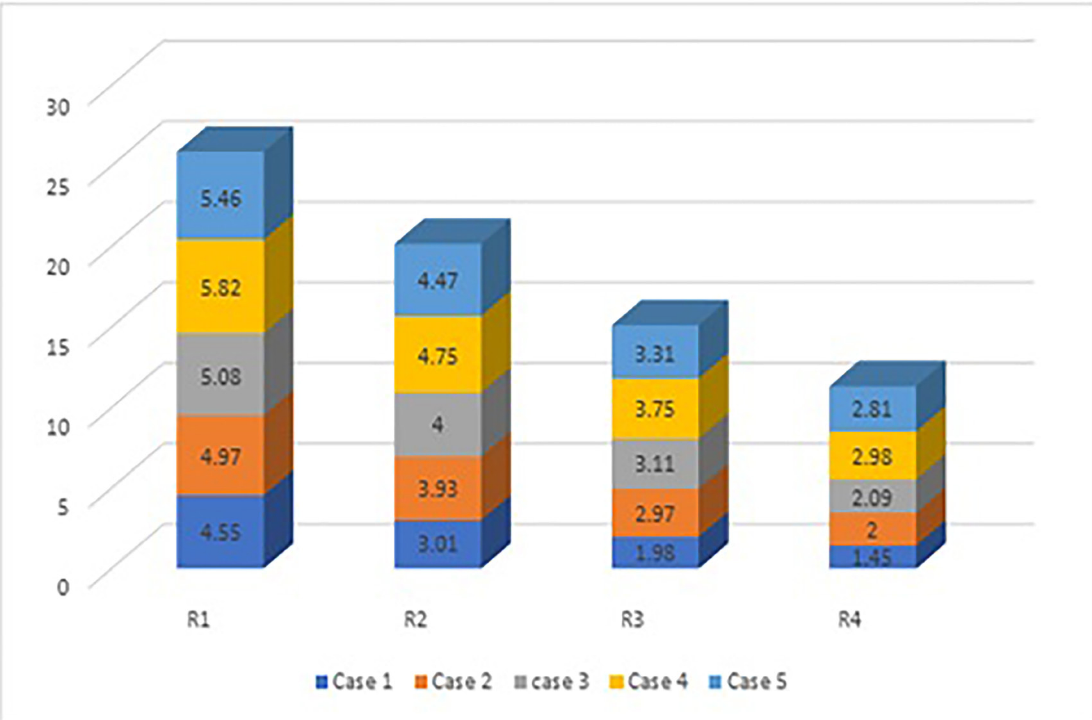

Figure 7: Average tensile strength of conventional concrete and fiber wrapped concrete at 500°C for 1, 2 & 3 hours.

R2: Tensile Strength (N/mm²) after heating at 250°C for 1 hour

R3: Tensile Strength (N/mm²) after heating at 250°C for 2 hours

R4: Tensile Strength (N/mm²) after heating at 250°C for 3 hours

The results in Table 6, shows that the fiber wrapped specimens withstands elevated temperature compared to conventional concrete for 500° for 1, 2 & 3 hours for the tensile test.

Here in the above graph shown in Figure 7, the following are the specifications

Case 1: Conventional Concrete (Without fiber) N/mm²

Case 2: Wrapped sample (Basalt) N/mm²

Case 3: Wrapped sample (Aramid) N/mm^2

Case 4: Wrapped sample (Basalt + Aramid) N/mm^2

Case 5: Wrapped sample (Aramid + Basalt) N/mm^2

R1: Tensile Strength (N/mm^2) for Conventional concrete

R2: Tensile Strength (N/mm^2) after heating at 500° C for 1 hour

R3: Tensile Strength (N/mm^2) after heating at 500° C for 2 hours

R4: Tensile Strength (N/mm^2) after heating at 500° C for 3 hours

Several case studies relevant to the proposed research work highlight the efficacy of hybrid FRP materials in various applications. The Burj Khalifa in Dubai, the world's tallest building, utilizes hybrid FRP materials in its construction. Hybrid FRP rebars reinforce the building's concrete structure, offering superior fire resistance compared to traditional steel reinforcement. This case study underscores the successful integration of hybrid FRPs in a high-rise building, meeting stringent fire safety standards.

Researchers at the University of Toronto conducted experimental studies examining the fire performance of concrete beams reinforced with hybrid FRP materials. These tests involved subjecting specimens to fire exposure and measuring parameters like temperature distribution, residual strength, and deformation. Results revealed the enhanced fire resistance of hybrid FRP-reinforced beams compared to conventional ones. Various case studies have investigated the effectiveness of hybrid FRP materials in repairing and retrofitting fire-damaged concrete bridges. Examples include rehabilitation projects in Europe and North America, where hybrid FRP systems were employed to restore structural integrity and fire resistance. These studies highlight the practical application of hybrid FRPs in enhancing the fire performance of existing concrete infrastructure. Researchers at the Technical University of Munich conducted experimental studies evaluating the fire resistance of hybrid FRP-reinforced concrete columns. Tests involved subjecting columns to simulated fire conditions and assessing parameters like temperature distribution, spalling behavior, and residual strength. Results indicated improved fire resistance in hybrid FRP-reinforced columns compared to conventional ones. Future works can be carried out by performing the tests for extreme environmental conditions like place of moisture variation, and place of chemical exposures. By changing the FRP (Carbon and Glass fiber) for hybrid wrapping further works can be done.

4. CONCLUSION

The Compressive Strength, Split Tensile Strength, Flexural Strength Test of fire exposed specimens wrapped with aramid fiber over basalt fiber shows more strength as compared to the fire exposed specimen at temperatures 250° C and 500° C than concrete without and with other wrappings. Due to the fire resistance properties of Fiber, strengthening of concrete specimens shows better performance and more strength as compared to the normal specimens when exposed to fire at various temperatures. Hence, the use of aramid fiber over basalt fiber is recommended to enhance the strength and to prolong the time of concrete elements damage caused exposed to fire.

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