RETROFITTING OF THERMALLY AFFECTED STRUCTURAL COMPRESSION MEMBER USING BASALT FRP LAMINATES

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Abstract: Concrete structures exposed to high temperatures often experience thermal damage, which can significantly reduce their structural integrity. Fiber-Reinforced Polymer (FRP) wrapping is a common retrofitting technique used to restore the strength and durability of thermally affected concrete. This study investigates the effectiveness of Basalt Fiber-reinforced Polymer wrapping on different concrete specimens with varying orientations of wrapping. This study mainly focuses on various parameters as fiber orientation and wrapping methodology. A series of 15 columns of dimension 150mm x 150mm with a length of 700mm are cast and subjected to axial compression loading in a pre-heated condition until the initial cracking occurs. These cracked columns are made to strengthen using Basalt Fiber with different patterns of orientation of laminates. The retrofitted columns are subjected to axial compression loading to determine their maximum load-bearing capacities. The test results of this experiment is assessed and compared with conventional RC columns of same grade. The strength of retrofitted columns versus conventional ones are compared and analyzed. The maximum load bearing capacity for a particular pattern of wrapping is determined.

Keywords: *Basalt Fiber; RC Jacketing; Axial compressive loading, fiber laminate, initial cracking.*

1 Introduction

One of the most crucial aspects of building structure design is durability, which may be restored by employing fiber-reinforced polymer to retrofit existing reinforced concrete (RC) constructions. Due to overloading in the structure results in local fractures over the design life of RC structures [1-3]. These fissures lessen a structure's ability to support loads, altering its dynamic properties and thus jeopardizing its long-term stability and safety. The main application of FRP composites is restoration, strengthening of various structural members of building that has shown intriguing and promising results since the initial attempts in the mid-1980s [5]. This has allowed for a significant improvement in the structure's strength and

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rigidity. The main technique for strengthening a column using FRP is to apply unidirectional FRP sheets to its rotating side [4-6]. To evaluate the debonding /failure properties of FRP and the mechanical behavior of reinforced RC structural elements, numerous analytical and experimental models have also been proposed recently [8]. Yet, standard carbon-based and glass-based methods are usually the only ones used to evaluate the performance of RC beams. Concrete is considered to be most commonly used materials in the field of construction. Concrete may cause failure over withstanding for a long period demolishing the existing structure and constructing a new one is quite expensive [2]. In order to overcome this effects rehabilitation is the most adoptive and economical techniques that is carried out to maintain building integrity, load bearing capacity and resist further Structural damage. Using Retrofitting both safety and durability of the structure is maintained and increased. Retrofitting is the strengthening techniques adopted to existing structures or structural elements to enhance their performance. Retrofitting is broadly categories as Global retrofitting and local retrofitting. Global retrofitting technique deals with providing resistivity towards seismic [4-6]. This technique has steel jacketing and base isolation which act as shear resistance an increase the durability of existing structures. Whereas local retrofitting deals with laminate warping on the particular shear zone where it tends to have a local failure or where the structures leads to failure.

In order to rehabilitate the structure several types of fibers are used and one of the commonly used natural, lightweight fiber is Basalt fiber (BFRP) [3]. Basalt fiber is the raw material for basalt rock. The basalt fiber is said to have a tensile strength of 994.2 MPa, the modulus of elasticity is noted as 7600 MPa, when compared with rest of the fibers it is economical and its chemical properties are matching with that of glass fiber which is considered to be a substitute material for glass. Major merits of Basalt fiber are greater shear strength, greater alkaline resistivity and to provide resistance towards radiations [12]. These Basalt fiber laminates are used to retrofit initially failed structures by means of various types of wrapping. This study aims to examine the compressive behaviour of externally wrapped basalt fiber reinforced polymer laminates with that of conventional specimen [1-2]. Which results to ascertain the increased strength of the compression member wrapped in BFRP when the parameters are varied according to the appropriate orientation [10]. To investigate how fiber orientation affects strength, ductility, failure mode, and stress-strain behavior. It also determine the performance of the structural member under different loading conditions.
Thermally affected concrete is concrete that has been subjected to high temperatures, which can cause damage to its structural integrity [6] [8]. This can occur due to exposure to fire, as well as other sources of high temperature such as the heat generated by nearby equipment or machinery. When thermally affected concrete is subjected to high temperatures, it can lose its strength and become more vulnerable to cracking and failure [11]. Retrofitting with BFRP can help restore and even enhance the strength of the concrete element [12]. For infrastructure and buildings to be able to withstand loads, structural compression members are necessary. These components may eventually become degraded as a result of a variety of circumstances, including corrosion, exposure to fire, and other environmental causes. Thermal deterioration can occur in structural compression members exposed to high temperatures, hence reducing their load-bearing capability. BFRP wrapping is a popular retrofitting technique for enhancing the strength of thermally affected concrete. The technique involves wrapping a concrete element with BFRP sheets, which are then anchored to the concrete using epoxy or other bonding agents [14] [20-21]. It is a common method used to retrofit and strengthen concrete structures. BFRP wrapping is an effective method for retrofitting thermally affected concrete because it can provide additional strength and stiffness to the concrete element, while also providing protection against further damage [3].

The BFRP sheets are lightweight and have a high strength-to-weight ratio, which makes them ideal for use in retrofitting applications. It is also corrosion-resistant, which makes it ideal for use in harsh environments [2]. In addition to enhancing the strength of thermally affected concrete, BFRP wrapping can also improve the durability of the concrete element by providing protection against corrosion, weathering, and other forms of environmental degradation.

2 Materials and Properties

1.1. Chemical properties of cement:

Cement is considered to have Tricalcium silicate (C3S), this compound provides early strength and contributes to the initial set of cement. It is responsible for the early strength gain in concrete. In regular Portland cement, 3% to 4% of gypsum is added; in quick-setting cement, the amount is lowered by 2.5 %. The fineness of cement particles influences the rate of hydration and the strength development of concrete. Cement fineness is measured as 100g of cement through a 90-micron sieve for 15 minutes. If the residue is 6% and the cement is suitable for use in building and it is well graded cement for use of concrete.

1.2.Physical properties of cement:

Specific Gravity: The specific gravity of cement is a measure of its density compared to water. It affects the volume and weight of concrete mixtures. The specific gravity of the materials used in retrofitting thermally affected structural compression members using BFRP laminates, including the concrete and the Basalt FRP laminates, is an important consideration for assessing the weight and density of the retrofitting components. Specific gravity (G) that compares the density of a material to the density of water. The specific gravity of the concrete is 3.14.
Consistency of cement: The consistency of the cement was measured and reported as 6 mm and 33%. These values represent two different approaches to quantifying the consistency or workability of the cement paste or mortar.

1.3.Initial Setting Time:

The setting time of the cement is initially 55mins. This is the time it takes for the concrete mix to change from a plastic, workable state to a semi-solid state. It's an important stage for placing and shaping the concrete around the Basalt FRP laminates.

1.4. Final Setting Time:

The setting time of the cement is finally 5hrs 25mins and 70sec. This is the time it takes for the concrete mix to change from a plastic, workable state to a solid state. It's an important stage for placing and shaping the concrete around the BFRP laminates.

1.5. Properties fine aggregate:

Sieve analysis: The values obtained from a sieve analysis, the cumulative percentage of fine aggregate retained on each sieve 0.2 % and the total percentage is 2.69% and the fineness modulus is 2.65%, which is a measure of the fineness of the aggregate. So the fine aggregate

is defined as well graded soil for the retrofitting of thermally affected structural compression member using basalt frp laminates.
Specific gravity: The specific gravity of the fine aggregate is observed as 2.55 which is well graded.
Bulk density: Bulk density refers to the mass of cement per unit volume, and it influences the workability and strength of concrete. The bulk density of the fine aggregate observed as 1530 kg/m^3 and which suitable for the retrofitting thermally affected structural compression members using BFRP laminates.

1.6. Properties coarse aggregate:

Sieve analysis: The values obtained from a sieve analysis, the cumulative percentage of coarse aggregate retained on each sieve 0.2 % and the total percentage is 2.99% and the fineness modulus is 2.79%, which is a measure of the fineness of the aggregate. So the coarse aggregate is defined as well graded soil for the retrofitting of thermally affected structural compression member using basalt frp laminates.
Abrasion Test: The abrasion test of coarse aggregate is a measured and it is found to be 29%.

1.7. Basalt FRP Laminates:

The specific gravity of BFPR laminates will depend on the specific type and manufacturer of the laminate. The specific gravity of the basalt fiber is 2.1. It's important to consider specific gravity when calculating the weight and load-bearing capacity of the retrofitting elements and the structure as a whole. This information is crucial for structural analysis and design.

1.8. Mix Ratio of concrete:

In this study, an M40 grade concrete mix was used, following a mix proportion of 1:1.85:2.60 [13-14]. This mix ratio indicates the proportions of cement, fine aggregate (sand), and coarse aggregate (20 mm size) required to achieve the desired M40 grade strength.

3 Experimental Program:

In this study a total 15 specimen were cast as a compression member of length 700 mm and dimension of 150 mm x 150 mm with the calculated mix proportions. These specimens are made to undergo 28 curing. Out of those 15 specimens 10 specimens were heated in oven for a temperature of 300 degree Celsius for 2 hours. After 2 hours of time the specimen is removed from the oven and cooled at room temperature. All 15 specimens out of which 10 is heated and 5 were undergone curing is taken and made to be wrapped with BFRP laminates. There were 4 different types of orientation / patterns for BFRP that are to be wrapped. The specimens were named as C1, C2, C3, C4 and C5. Where C1 is conventional concrete, C2 – BFRP laminate which is wrapped only on the shear zone which is top and bottom for the width of 150 mm, C3 – BFRP laminate which is wrapped at an equal spacing of 100 mm from the top, C4 – BFRP laminate which is fully wrapped along the compression member and C5 – BFRP laminate which is wrapped as double layer on compression member. These externally wrapped compression members are made to undergo axial loading under hinged support condition and their maximum load carrying capacity for each column of heated and unheated were recorded. The compressive results were tabulated.

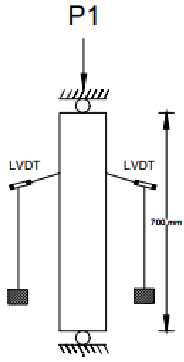

Figure 1. Experimental Setup

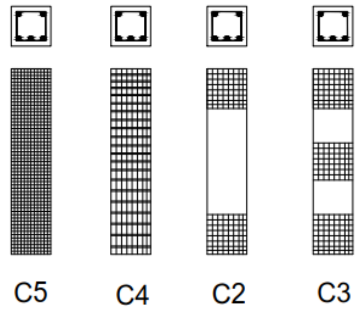

Figure 2. Specimen Model

Table 1. C1 – Conventional Concrete

S.No	Grade of concrete	Ultimate load (kN)	Compressive strength (N/mm^2)
1	M_{40}	395	39.45
2	M_{40}	409	40.25
3	M_{40}	391	38.74

Table 2. C2 - The column wrapped on top and bottom

S.No	Grade of concrete	Ultimate load (kN)	Compressive strength (N/mm2)
1	M_{40}	488	45.55
2	M_{40}	495	47.95
3	M_{40}	505	50.41

Table 3.. C3 - The column wrapped on equal spacing

S.No	Grade of concrete	Ultimate load (kN)	Compressive strength (N/mm2)
1	M_{40}	611	58.74
2	M_{40}	606	55.41
3	M_{40}	598	53.25

Table 4. C4 - The column wrapped single layer

S.No	Grade of concrete	Ultimate load (kN)	Compressive strength (N/mm^2)
1	M_{40}	405	43.25
2	M_{40}	425	45.14
3	M_{40}	415	44.01

Table 5. C5 - The column wrapped Double layer

S.No	Grade of concrete	Ultimate load (kN)	Compressive strength (N/mm^2)
1	M_{40}	452	49.74
2	M_{40}	445	47.50
3	M_{40}	448	48.65

4 Results and Discussions

The comprehensive investigation were carried out to determine the compressive strength of concrete that has yielded valuable insights and critical data. Through rigorous experimentation and analysis, various concrete mixtures were tested under different curing conditions and ingredient compositions. The compressive strength of each sample was measured using standardized compressive testing procedures axial with hinged support. The results were tabulated.

4.1 Compressive Strength (Without Heating)

Table 6. Compressive strength without heating

S.No	Specimen Name	Compressive Stress (N/mm2) *Without Heating*	Compressive Stress (N/mm^2) *With Heating*	%Increase
1	C1	37.58	39.48	105.05
2	C2	44.36	47.97	108.14
3	C3	49.94	55.80	111.73
4	C4	42.14	44.13	04.72
5	C5	45.36	48.63	107.21

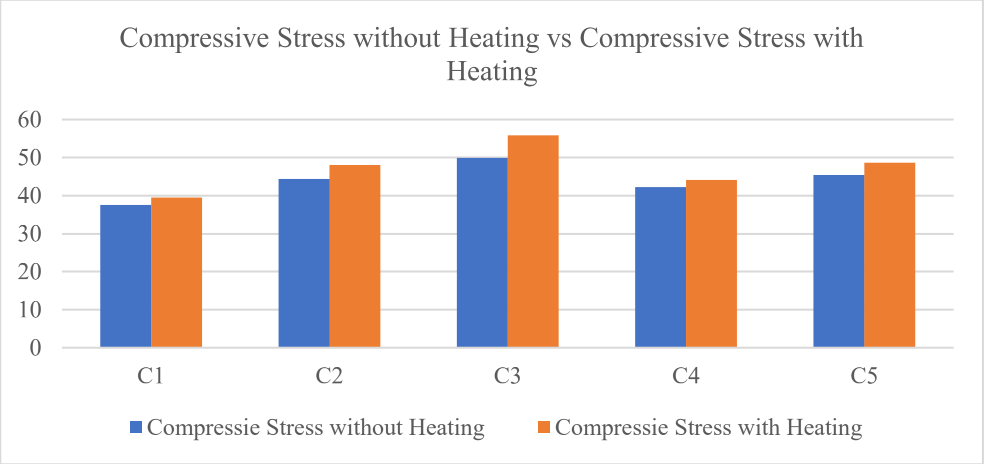

Figure 3. Compressive Stress without heating vs Compressive Stress with heating

5 Conclusion

From the tested results it is inferred that when compared to the conventional columns the columns which are wrapped with BFRP provides greater compressive strength. By this retrofitting process, if one particular compression member of an entire structure get damaged it is not necessary to remove that entire structure instead retrofitting of selected approach can be utilized. The results shows that compressive strength of column with heating has increased by 196.14 %, 113.49 %, 139.98 %, 126.44 % and 133.37 % when compared with retrofitted column without heating. Thermally affected compression member's load-bearing capacity is greatly increased by BFRP laminates, because of its high modulus and tensile strength. It is also recorded that the compressive strength heated column that is wrapped with BFRP provides higher compressive strength compared with columns that are not heated. From these results we can concluded that the compressive strength of double wrapped heated columns indicates greater load carrying capacity compared with all other columns with various types of orientations.

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