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COMPRESSIVE BEHAVIOUR OF RC COLUMNS CONFINED WITH BASALT FIBRE REINFORCED POLYMERS

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Abstract

As a reinforcing agent for the production of lightweight and low-cost polymer composites, there has been a recent increase in the use of environmentally friendly natural fibers around the world. One of the interesting materials that are currently widelyused is basalt, which offers inexpensive and excellent glass properties. The outstanding advantages of this composite material include high mechanical physicochemical properties, biodegradability and non-abrasive properties. This article presents the compression behavior of reinforced concrete columns (RCC), limited by basalt, used as reinforcement for composite materials. This paper also explores the basic and structural properties of underlying basalt fibers. It also encompasses efforts to showcase new trends in scientific research publications and activities in the field of basaltfibres.Further sections discuss the height of the RC column (0.9m, 1.2m, 1.5m and 1.8m) and number of plies (single and double plies) investigation is done. Comparatively short RC columns (height = 0.9m) confined with basalt fiber reinforced polymers have higher compressive strength than the other RC columns confined with basalt fiber reinforced polymers for both single and double plies.

Keywords: BFRP; RC column; Strengthening; Confinement; Compressivestrength.

Introduction

Many older structures today require strengthening of their existing civil engineering infrastructure. This need arises due to factors such as aging, corrosion from environmental factors, increased stress from functional changes in design, or deficiencies from poor designs that no longer meet modern, stringent requirements, particularly in seismic areas. To withstand higher structural loads or enhance ductility, reinforcement or modernization of old structures has been performed using traditional materials, such as steel sheets and steel shells, since the 1960s. Various methods have been developed to improve columns, increase axial strength, enhance ductility, and prevent the bending of longitudinal reinforcement [H. Saadatmanesh, 1994].

Traditional methods include sealing with steel or reinforced concrete shells. More recent technologies involve external closures, where a fiber-reinforced polymer (FRP) is wrapped around a column to create an outer reinforced casing [M. Demers, 1999; A. Nanni, 1995]. Wrapping composite panels around concrete columns is a promising structural reinforcement method due to GRP's unique properties, such as strength, lightness, chemical resistance, and ease of use. This method is particularly attractive because of its quick implementation and low labor costs [Lau, K. T, 2001].

Mechanism of BCF

Basalt fiber is a material made from very fine basalt fiber, consisting of minerals such as plagioclase, pyroxene, and olivine. It resembles fiberglass and offers better physical and mechanical properties compared to fiberglass, while being more cost-effective than carbon fiber. Basalt fiber is used in aerospace and automotive industries as a flame-retardant fabric and can also be used as a composite material for manufacturing products like tripod cameras.

BCF (Basalt Continuous Fiber) production technology involves a one-step process: melting, homogenizing basalt, and extracting the fiber. Basalt is heated only once during this process. BCF is then processed into materials using "cold technology," which has low energy costs. Basalt fibers are derived from a single material, broken basalt, sourced from carefully chosen quarry sites. High-acidity basalt (with more than 46% silica) and low iron content are preferred for fiber production. Unlike other composite materials such as glass fiber, no additional ingredients are added during manufacture. The basalt is washed and melted at around 1500°C (2730°F). The molten rock is then extruded through a small nozzle to produce continuous basalt fiber filaments.

Basalt Fiber Structure and Properties

Basalt fiber has been employed as a reinforcing material in concrete technology for many years. It is a high-performance, environmentally friendly material derived from natural basalt. Basalt fiber is valued for its high tensile strength, excellent modulus of elasticity, and superior corrosion resistance. The three primary manufacturing techniques for basalt fiber are centrifugal spinning, multi-rolling centrifuges, and spinning. Typically, basalt fibers have a diameter ranging from 9 to 13 µm, which exceeds the 5 µm respiratory limit, making basalt fibers a suitable alternative to asbestos. They exhibit high modulus of elasticity, producing specific strengths that are approximately three times greater than those of steel. Basalt fiber, continuously obtained from basalt rock, has demonstrated significant technical and performance properties. The key properties of basalt fiber include:

- **Fiber Diameter (µm):** 9

- **Specific Weight:** 2.65
- **Thermal Stability:** High thermal stability with low flammability; degradation with low strength at temperatures from -200°C to 250°C and high strength at temperatures from +700°C to 900°C, even under high humidity.
- **Operating Temperature (°C):** -200 to +900
- **Heat and Sound Insulation:** Excellent heat and sound insulation properties. Sound insulation ranges from 80% to 95% for frequencies between 400-1800 Hz.
- **Adhesion:** Very good adhesion to polymer resins and rubbers.
- **Mechanical Strength and Durability:** Relatively high mechanical strength, abrasion resistance, and elasticity. Resistance ranges from 0.67 to 0.93 N/tex.
- **Fracture Extension (%):** 3.1
- **Initial Modulus (N/tex):** 30-35
- **Dielectric Property:** High dielectric property.
- **Moisture Recovery (%):** 1
- **Water Absorption:** Low water absorption.
- **Chemical Resistance:** High chemical resistance, especially against concentrated acids.
- **Environmental Impact:** Environmentally friendly and non-toxic.

3.1 Materials and Methods

Material Properties: The characteristic compressive strength of the concrete used in this study was 25 MPa. The mix ratio adopted was 1:1.4:2.75:0.46 (cement: fine aggregate: coarse aggregate: water). The compressive strength of the concrete cubes after 28 days of water curing was 33.64 MPa.

Preparation and Casting of RC Columns: RC columns were cast using PVC molds with a diameter of 120 mm and heights of 0.9 m, 1.2 m, 1.5 m, and 1.5 m. Six 8 mm diameter bars were used as longitudinal reinforcements, and 6 mm diameter ties with 200 mm spacing were used as transverse reinforcement. A liberal coat of lubricating oil was applied to the interiors of the PVC molds to prevent concrete from adhering to them. The designed concrete mix was poured into the molds in layers, and compaction was achieved using a needle vibrator to avoid honeycombing.

Properties of Basalt Fiber Reinforced Polymer (BFRP): Basalt fiber reinforced polymers were utilized in the study. The properties of the BFRP materials are detailed in Table 1.

Table 1. Properties of BFRP Material

Properties	**Unidirectional BFRP Mat**
Weight of Fiber (g/m²)	330
Fiber Thickness (mm)	0.6
Nominal Thickness per Layer (mm)	1.0
Fiber Tensile Strength (N/mm²)	4840
Tensile Modulus (N/mm²)	86000

4. Fiber Reinforced Plastic (FRP) Wrapping

Fiber-reinforced plastics (FRP), also known as fiber-reinforced polymers, are composite materials consisting of a fiber-reinforced polymer matrix. Common fibers include glass (in glass fiber), carbon (in carbon fiber reinforced polymers), aramid, or basalt. Less commonly used fibers include paper, wood, or asbestos. Polymers used are typically epoxy, vinyl ester, or polyester plastics, though phenol-formaldehyde resins are still employed in some cases. FRPs are also frequently used in ballistic armor.

Rigid structures often determine the shape of FRP components. Parts can be placed on a flat surface called a "welding plate" or on a cylindrical structure known as a "mandrel". Most FRP parts are molded or printed, with shapes that can be female concave, male, or fully encapsulating the top and bottom.

Rubbing: The surface of the RC column is rubbed with silicon carbide paper to remove loose and hazardous sheets.

Primer Coating: Nitowrap 30 primary primer is applied to the prepared and cleaned surface, which is then allowed to dry for approximately 24 hours before applying the Nitowrap 410 saturated. The primary properties of Nitowrap 30 are summarized in Table 4.

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Table 4. Properties of Nitowrap 30 Primer

Property	Value
Density	1.14 g/cc
Pot Life	25 minutes @ 27°C
Full Cure	7 days

Saturant Coating: The Nitowrap 410 system consists of two components: resin and hardener. These components are mixed by hand for 3 minutes before application. The properties of Nitowrap 410 are detailed in Table 5.

Table 5. Properties of Nitowrap 410 Saturant

Property	Value
Colour	Pale yellow to amber
Application Temperature	15°C - 40°C
Viscosity	Thixotropic
Density	1.25 – 1.28 g/cc
Pot Life	2 hours @ 30°C
Full Cure	5 days @ 30°C

5. Experimental Setup and Results

The RC column was arranged vertically between the loading frame's loading area. Axial pressure loads were applied vertically and evenly until the RC column failed. An experimental study was conducted on column 12RC. From the 12RC columns, four control columns were tested after 28 days of compaction without any closure, while the remaining eight columns were restricted to single and double BFRP layers. The restricted and unrestricted BFRP RC columns are illustrated in Fig. 1.

Unconfined RC columns

BFRP confined RC columns

Fig.1. FRP confined RCcolumns

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Table 4. Results of Tested RC Columns

Sl. No.	Type of Confinement	Height of the RC Column (m)	Number of Plies	Compressive Strength (kN)
1	Unconfined RC columns	0.9	-	280
		1.2	-	252
		1.5	-	221
		1.8	-	183
2	RC columns confined with unidirectional BFRP mat along the circumference	0.9	1	426
			2	573
		1.2	1	382
			2	515
		1.5	1	337
			2	454
		1.8	1	280
			2	376

Effect of Height of RC Column on Compressive Load Capacity

To investigate the effect of RC column heights on compression resistance, RC columns with a diameter of 0.12 m and varying heights of 0.9 m, 1.2 m, 1.5 m, and 1.8 m were considered. The results are presented in Table 4. It is observed that the axial load capacity decreases with increasing RC column height. This decrease is attributed to the increasing slenderness of the RC columns. Additionally, it is noted that non-reinforced RC columns exhibit significantly lower compressive strength compared to RC columns confined with BFRP, even when the heights are the same.

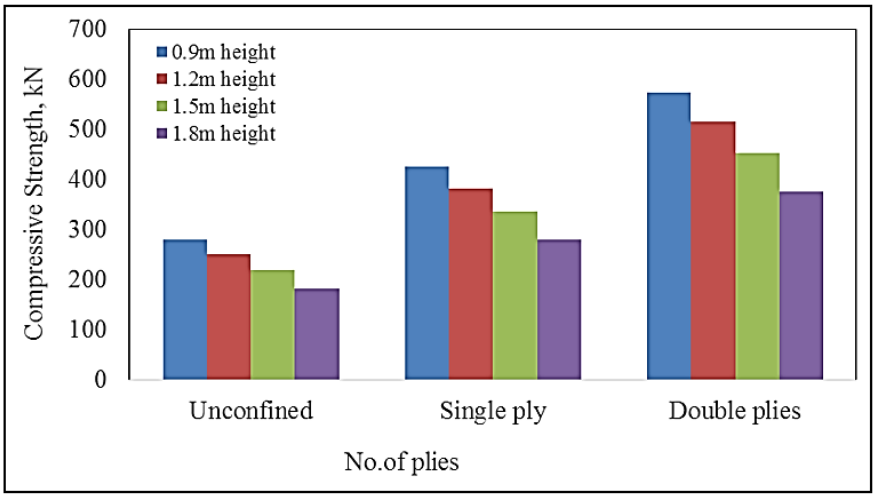

Fig. 6. Compressive strength of RC columns confined with BFRP

Effect of Height of RC Column on Compressive Load Capacity

- The percentage reduction in compressive strength of RC columns with heights of 1.2 m, 1.5 m, and 1.8 m, compared to RC columns with a height of 0.9 m, is 11.11%, 26.69%, and 53%, respectively.

- The percentage reduction in compressive strength of BFRP-RC columns with heights of 1.2 m, 1.5 m, and 1.8 m, compared to a 0.9 m BFRP-RC column, is 9.86%, 20.89%, and 34.27% for a single layer, and 10.12%, 20.76%, and 34.38% for a bilayer, respectively.

Effect of Number of Plies on Compressive Load Capacity

To determine the effect of the number of layers on the compressive strength of an RC column, the columns were reinforced with either one or two layers of basalt fiber. The experimental results indicate that RC columns with double layers exhibit higher compressive strength compared to those with a single layer. This improvement is attributed to the increased thickness of the reinforcement when wrapped in a BFRP mat. Figure 4 illustrates the variations in compressive strength of RC columns reinforced with single and double layers of BFRP.

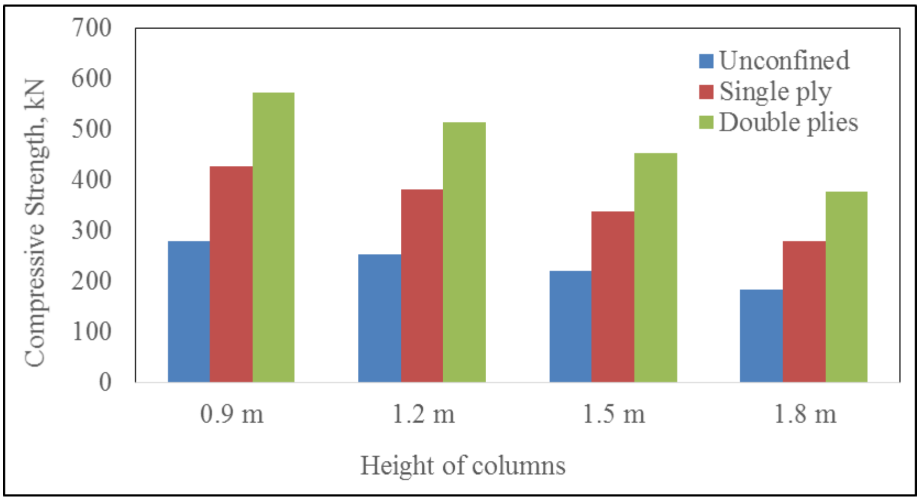

Fig. 4. Compressive Strength of RC Columns Confined with Single and Double Plies of BFRP

- The percentage increase in compressive strength for a 0.9 m RC column confined with one and two layers of unidirectional BFRP mats is 52.14% and 104.64%, respectively, compared to non-confined RC columns.
- The percentage increase in compressive strength for a 1.2 m RC column confined with one and two layers of BFRP mats is 52.38% and 104.36%, respectively, compared to non-confined RC columns.
- The percentage increase in compressive strength for a 1.5 m RC column confined with one and two layers of unidirectional BFRP mats is 52.48% and 105.42%, respectively, compared to non-confined RC columns.
- The percentage increase in compressive strength for a 1.8 m RC column confined with one and two layers of BFRP mats is 53% and 105.46%, respectively, compared to non-confined RC columns.

Mix Proportions

Mix proportions for M60 grade concrete were determined using the Absolute Volume Method of mix design [4], with 20%, 25%, and 30% of the cement mass replaced by Silica Fume (SF). The material requirements per cubic meter of concrete are provided in Table 1.

V. CONCLUSIONS

This study involved 12 RC columns confined with BFRP. The following conclusions are drawn from the experimental results:

- **Axial Load Capacity:** The axial load capacity decreases with increasing height of the RC column due to increased slenderness. Unconfined RC columns exhibit significantly lower compressive strength compared to columns confined with BFRP of the same height.

- **Effect of Ply Layers:** RC columns confined with two layers of BFRP demonstrate higher compressive strength compared to those confined with a single layer. This improvement is attributed to the increased thickness of the reinforcement provided by the BFRP wrap.

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