International Journal of Scientific Research and Engineering Development-– Volume 5 Issue 1, Jan-Feb 2022
Available at www.ijsred.com

RESEARCH ARTICLE OPEN ACCESS

PERFORMANCE DUE TO FIRE ON BASALT-STRENGTHED REINFORCED CONCRETE COLUMNS

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Abstract:
Basalt fiber reinforced polymer (BFRP) materials are regarded as promising structural strengthening materialdue to their environmental friendly and superior mechanical and chemical properties.Fire resistance of concrete members strengthened with BFRPwraps is an extremely crucial area that needs to be investigated prior to implementing FRP materials in buildings and other fire vulnerable structures.This research provides aninvestigation for the effects of high temperature on concrete and concrete structures, extending to a range of forms of construction, including novel developments. A total of six BFRP-strengthened circular reinforced concrete columns exposed to fire were tested under concentric axial load. The specimens were divided to two groups having the same cross section as a diameter of 150 mm and height of 900 mm. The test parameters included effect of BFRP wrapping, temperature, and BRP wrapping thickness, and coolingmethod (air or water). The test results indicated that using basalt fiber sheets as a strengthening method has a positve effect on the column's ultimate capacity.

Key words: BRP, Circular column, Confinement, Fire, High temperature, Wrapping.

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INTRODUCTION

Fire in buildings is nearly always resulting from negligence or error. This can cause immense damage in terms of lives and property. With a fire, the main problem to face is the combustibility of the contents and failure of the structure. Extend of ensuing damage depends primarily on the structural performance of the building both during and after the fire. One of the main principles of fire precautions is understand the behavior and characteristics of the building materials during and after the fire crises, to react with them at the new case.Previous research on reinforced concrete members were conducted for the purposeof updating the fire resistance classifications for these members. These studies include the development of both experimental and mathematical modelings for the calculation of the fire resistance of concrete elements of various sizes and shapes. In addition, more attention has been paid to the fundamental fracture properties of concrete at room temperature. However, research on these properties under elevated temperatures only started in the late 1970s, and has since become more frequent. The information about these properties is very useful for the design of special concrete structures sustaining various high temperature environments such as nuclear reactor structures, the chemical industry and fire protection. The behavior of a reinforced concrete structure in fireconditions is governed by the properties of the constituent materials – concrete and steel (reinforcement) – at a high temperature. Both concrete and steel undergo considerable reduction in their strength, physical properties and stiffness by the effects of heating and some of the changes are not recoverable after subsequent cooling. Chemical changes may also occur, especially in siliceous aggregate concrete, due to heating. An understanding of these changes is essential in predicting or assessing the performance of the structure during fire and subsequent cooling. When a structural component is exposed to devastatingfires accidentally for long periods (exceeding fire resistance duration) resulting in high rise of temperature and reduction in strength, the data on residual strength of reinforced concrete members which is defined as ‘‘the reduced strength’’, are not always available before deciding rehabilitation of any component of the structure damaged due to fire.

Columns are significant auxiliary components since they are the primary supporting components in RC structures. Erosion of customary steel causes splits in sections, which for the most part prompts disappointment in basic segments. These days, new materials are created to upgrade the presentation of auxiliary components. Confinement is generally applied to members in compression, with the aim of enhancing their load carrying capacity or, in cases of seismic upgrading, to increase their ductility. Traditional confinement techniques rely on their either steel hoops or steel jackets for upgrading. Indeed, it is well known that increasing the confinement action enhance that concrete strength and ductility and, in addition, prevents slippage and buckling of the longitudinal reinforcement. In seismic problem, Existing confinement pressure in either the potential plastic hinge or over the entire member (e.g. Cgai et al. 1991). This technique can also be useful in lap-splices zones [1]. A new technique for external confinement of reinforced concrete columns has been recently used widely, such technique is the application of circumferential wrapping with ACM (Advanced Composite Materials) such as BSRP (Basalt Sheets Reinforced polymers). Such technique relatively to old techniques is easy to apply. The most interesting advantages of these composite materials are the flexibility, lightweight, thin thickness, the non-corrosive nature, and ability to apply to columns by any shape easily.

A review of the state of the art concerning basalt fibers and their use as reinforcement phase in composite materials for applications in civil engineering field has been provided. Basalt fibers, obtained from melted natural basalt rocks and characterized by significantly cheaper production processes in comparison with other fibers (e.g., carbon and glass), exhibit very appealing physico-chemical properties: good strength and stiffness, high temperature resistance, long-term durability, acid and alkali resistance, heat and sound insulation, as well as good processability. These aspects, in addition to the high eco-sustainability levels of basalt fiber production and using, have induced a widespread diffusion of basalt-based products [8]. Column wrapping utilizing carbon and glass FRP systems increases the maximum axial stress in columns in both circular carbon-fiber wrapped columns and rectangular carbon-fiber wrapped columns, the stress increases to 24% and up to 26.8% increase in an axial load testing [9]. The unconfined and CFRP confined concrete columns cast with different types of mixing water and sand exhibit similar failure patterns, which means that the seawater and sea-sand have a negligible effect on the short-term mechanical performance of the specimens, especially for the confined columns[10].

Newly developed BFRP composite can be effectively used in improving the overall compressive behavior of confined concrete [11].

It has been observed that for a CFRP-confined concrete column, the propagation of the initial defect may not lead to the global failure. In general, such a phenomenon alters the confining pressure provided by the FRP, leading to stress redistribution and weakening of the structure. Deformation behavior and final failure greatly depend on the initial defect size [12]. The axial behavior of the GFRP-confined expansive concrete was experimentally investigated. Results demonstrated that expansive concrete offered the active confinements, and thus compensates for the insufficiency of low FRP confinement, thereby leading to good post-peak performance in strain-hardening behavior, as compared to strain-softening one in the conventional concrete [14]. The carbon fiber reinforced polymer in the hoop direction can significantly increase the ductility of hollow core square reinforced concrete columns under concentric or eccentric loading. Compared to VHF and AHF columns, HF columns can sustain much larger deformation before failure. However, the increment of the compressive strength of FRP-confined hollow core columns is marginal [15]. An increasing trend of load carrying capacities is observed with increase in CFRP volumetric ratios at all eccentricities except at e=35mm wh

Effect of high temperature on concrete

The behavior of concrete is characterized by material property degradation with increased temperature. The stress–strain relationship is defined according to the Euro code 2 (ENV2001) [3] as shown in Fig. 1. Here, the initial elastic behavior is followed by a plastic-hardening curve up to the ultimate stress, after which, a decaying zone represents the post-crushing behavior for concrete. This relationship has the advantage of allowing the definition of a stress level for large plastic deformations, usually reached during fire conditions.

Malhotra [4] who investigated the effect of elevated temperatures on compressive strength of concrete by heating 5cm and 10 cm cylinders using various mix proportions and water-cement ratios. The test results have been expressed as percentage of unheated strength and plotted against the temperature. Also he noted that E-value of concrete also drastically reduces with temperature.

Effect of high temperature on steel

Like concrete, steel also loses strength with temperature. The magnitude of the loss and the rate of reduction depend upon the type of steel and its manufacturing process. Mild steel and hot-rolled high-tensile steel retain only 50% of its normal temperature (20 C) yield stress at about 600 C, but up to a temperature of about 300 C the strength (yield stress) appears to be slightly higher than at room temperature. For coldworked high-tensile reinforcement, 50% reduction of the yield stress usually occurs at a temperature around 550^{o} C. The rise in strength up to a temperature of 300^{o} C is also less. If reinforcing bars are heated up to 600^{o} C, they virtually recover their full normal temperature strength when cooled to room temperature again [8].

Effect of high temperature on loaded columns

In 2000 Karamoko et al. [2], studied reinforced concrete columns designed for stability against fire. A Monte Carlo simulation technique is used to assess the probability of failure by taking into account the effect of temperature on statistical distributions. The reliability of columns exposed to fire appears particularly affected by variations in the parameters such as the design exposure time, slenderness, and steel ratios. A possibility of reducing the sensitivity is proposed. Also Rashad in 2000 [5] evaluated the effect of elevated temperatures on loaded RC columns containing different aggregate types and different mineral admixtures, Muhammad, in 2002 [6] studied experimentally and analytically the residual vertical and lateral load capacities of short centrically loaded modeled reinforced concrete columns when the modeled columns were fired in an actual fire furnace under different circumstances during and after fire test.

In 2003 Helmi [7], focused on the effect of different protection materials on the structural response of retrofitted RC columns. Also Ibrahim and Marzouq, in 2003 [8], evaluated the effect of the method of fire extinguishing methods on the capacity of reinforced concrete compression members.

Fire protection materials

In 1999 Sakumoto [9], discussed fire-safe design methods incorporating the application of new fire-protection materials. New fire-protection materials targeted in the research are tumescent coating that foams when heated and a fire protection ceiling provided with plaster boards to isolate heating coming from the room.

EXPERIMENTAL WORK

Six R.C. columns with circular cross-section, sized 150mm (diameter) x 900mm (height), were manufactured and tested as shown in figure (1).

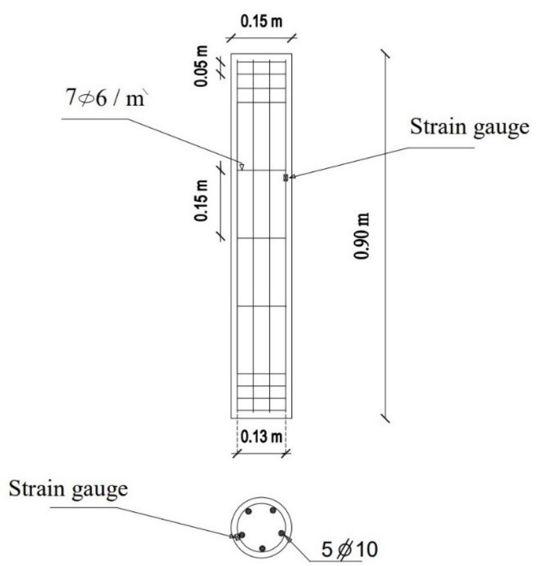


Figure1: Details of Typical Specimen.

Two parameters were considered in this study;. Details of tested specimens with different parameters are shown in table (1).

Table 1: Experimental program

Group .NO	Column .NO	Geometry (mm)	Strengthe-ning .Material	Strengthening .Shape	.Fcu	Temperature °c	Cooling .Method
G1 Control	A1	D = 150	——	——	250	25	——
	A2					500	Air
	A3					500	Water
G2 BFRP	B1	D = 150	Basalt Fiber	Three Strips Two Layers W=20 cm	250	25	——
	B2					500	Air
	B3					500	Water

The experimental work has been planned to investigate the difference in global behavior between conventional reference short circular columns constructed of normal strength concrete and those columns strengthened with Basalt fiber reinforced polymer.The test measurements include the first crack loads, failure loads, crack patterns, axial deformations, and concrete strains. Therefore, a total of six columns classified into two groups as shown in Table (1). The first group consists of three columns designated by A1,A2 and A3 Where G1 represents the behavior of control column reference specimens without any strengthening as shown in figure (2).The second group represents the Partial Strengthening Basalt Fiber group which consists of three columns B1,B2 and B3.

Where:

B1, B2 and B3: were strengthened with three strips of Basalt Fiber with two layers of 20cm width and spacing of 15 cm as shown in figure (3).

Figure(2): The first group.

Figure(3): The second group.

Table (2): Steel mechanical properties.

Property	Longitudinal steel	Stirrups steel
Yield strength (N/mm²)	**360**	**240**
Ultimate strength (N/mm²)	**520**	**350**
Elongation percent %	**20**	**23.2**

Table (3):Mechanical properties of BFRP wraps.

Property	Test results
Fiber type	Basalt Woven Fabric (BAS 220.1270.P)
Fiber weight (g/m²)	220
Fiber orientation	Two - way
Fabric design thickness (mm)	0,13
Fabric width (mm)	1270
Tensile strength of fiber (N/mm²)	2800-4800
Tensile E-modulus of fibers (N/mm²)	86000-90000
Elongation at break (%)	3.15%

The concrete mix was designed to achieve a target compressive strength of 25N/mm² after 28 days. The mix properties are shown in table (4).

Table (4): Concrete mix properties

Constituents	**units**	**Contents (m³)**
Cement	Kg	350
Sand	Kg	720
Water	Liter	175
Water-cement ratio	%	0.5
Coarse aggregate	Kg	1400

Each column is strengthened with 5Ø10 mm longitudinal fortifying plain bars giving support proportion of 0.022 longitudinal way. For all sections, tied stirrups were given of 11Ø6 mm plain bars. Pitches of stirrups were 5.0 cm at the section closes and 15cm along segment stature. Though the stirrups are accumulated at the segment finishes maintaining a strategic distance from neighborhood disappointment at the segment finishes because of stress focus.

The electrical strain gauges are used to measure different strains of the columns. One strain gauge is used for each specimen to measure strain of reinforcement, the location of strain gauges at the first third of the column. All columns were tested up to failure in axial compression using universal testing machine having 1200000Newton capacity. The upper head was fitted with seat. Both end surfaces of the columns are capped using gypsum layer to ensure horizontal and smooth surfaces. Care is taken to load the columns axially and reduce any possible eccentricity of the columns. A swivel is placed between the machine and the upper top of the column to ensure uniform loading. as shown in figure (2). The first Group consists of three columns which had tested as control specimens without strengthening to determine the effect of high temperature and way of cooling on the compressive strength of concrete. One column was tested at ambient temperature to determine the maximum load capacity before exposure to high temperature. Two columns were subjected to 500ºc temperature for a period of 60 min , one had cooled using water and the other was left to cool at ambient temperature at 25ºc. The second group had six columns which were partially strengthened with Basalt Fiber Reinforced Polymers sheets with two layers of 20cm width and 15 cm spacing. One column was tested at ambient temperature to determine the maximum load capacity before exposure to high temperature. Two columns were subjected to 500ºc temperature for a period of one hour, one had cooled using water and the other was left to cool at ambient temperature at 25ºc.


Figure(4):Details of the tested columns

Figure(5):Test setup with a tested column

TEST RESULTS AND ANALYSIS

In this part, the obtained test results are compared together and discussed to evaluate the effects of different types of strengthening on the column behavior. Columns responses are obtained in terms of load- displacement and ultimate load.

A. ULTIMATE LOADS AND STRENGTH

The load and strength capacities for tested columns as measured experimentally are given in Table(5) . As shown in Table (5) and plotted on figure (8), (9) and (10).

Column (**A1**) was tested as a control coulmun at ambient temperature without any strengthening. Micro cracks started near the bottom of the column and propagated vertically. The first crack initiated and could be seen at load of 30.17 tons, which represents 61% of the peak load. With further loading, the second crack initiated and could be seen at load of 42.19 tons at bottom of the column, the third crack initiated and could be seen at load of 45.23 tons at top of the column and spalling of concrete cover started, the forth crack initiated and could be seen at load of 48.42 tons at bottom of the column it was a horizontal crack and the complete collapse occurred at load of 48.97 tons.

Coulmn (**A2**) was tested as a control column after exposed to fire with a 500 c temperature for 60 min andwas left to cool at ambient temperature.Micro cracks started near both the bottom and the top of the column end and propagated vertically. The first crack initiated and could be seen at load of 16.52 tons, which represents 36% of the peak load and spalling of concrete cover started. With further loading, The second crack initiated at the top of the column and spalling of concrete cover started and could be seen at load of 19.23 tons, The third crack initiated and could be seen at load of 37.91 tons at the top of the column and spalling of concrete cover, The forth crack initiated and could be seen at load of 40.41 tons at the bottom of the column, the complete collapse occurred at load of 44.64 tons.

Coulmn (**A3**) was tested as a control column after exposed to fire with a 500 c temperature for 60 min andhad cooled with water. Micro cracks started the the top of the columnend and propagated vertically. The first crack initiated and could be seen at load of 19.52 tons, which represents 41% of the peak load and spalling of concrete cover started. With further loading, The second crack initiated at the bottom of the column and spalling of concrete cover started and could be seen at load of 24.63 tons, The third crack initiated and could be seen at load of 38.91 tons at the bottom of the column and spalling of concrete cover, The forth crack initiated and could be seen at load of 42.41 tons at the bottom of the column, the complete collapse occurred at load of 47.32 tons.

Coulmn (**B1**) one of the basalt fiber group coulmns which has strengthened partially without exposing to fire. Micro cracks started near the top third of the column and propagated horizontally. The first crack initiated and could be seen at load of 49.90 tons, which represents 84.86% of the peak load. With further loading, The second crack initiated at the middle of the column and could be seen at load of 54.50 tons, The third crack initiated near the lower third of the column and propagated horizontally and could be seen at load of 56.60tons, The forth crack initiated and could be seen at load of 57.61 tons at the middle of the column and the complete collapse occurred at load of 58.82 tons,It also shows that the enhancement in the ultimate strength capacity of the column strengthened with partial fibers are 20.1% with reference to **A1** as shown in table(5).

Coulmn (**B2**) one of the basalt fiber group coulmns which has strengthened partially after exposing to 500 c fire for 60 min and left to cool in ambient temperature Micro cracks started near the top third of the column and propagated horizontally. The first crack initiated and could be seen at load of 48.04 near the top third of the column which represents 92% of the peak load. With further loading, The second crack is continued the first crack and could be seen at load of 50.14 tons, The collapse occurred at load of 52.02 tons at middle of the columnandcut the middle basalt strip,It also shows that the enhancement in the ultimate strength capacity of the column strengthened with partial fibers are 16.5% with reference to **A2** as shown in table(5).

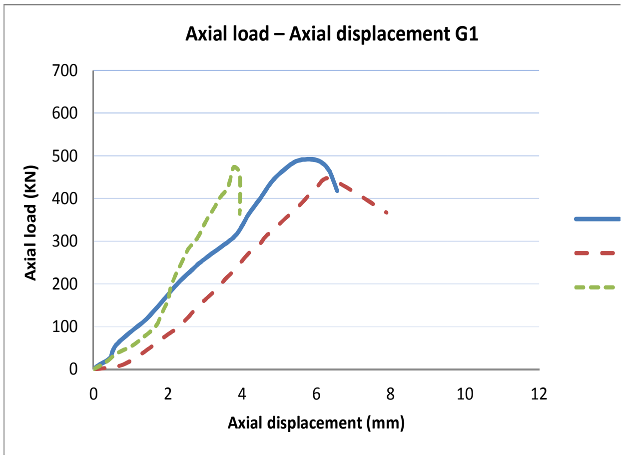
Coulmn (**B3**) one of the basalt fiber group coulmns which has strengthened partially after exposing to 500 c fire for 60 min and had cooled with water. . Micro cracks started the top and bottom slice of the column and propagated vertically. The first crack initiated and could be seen at load of 47.02 near the bottom third of the column which represents 84.88% of the peak load. With further loading, The second crack is continued the first crack and could be seen at load of 51.07 tons, The collapse occurred at load of 55.39 tons at the top of the columnandcut the top basalt strip, It also shows that the enhancement in the ultimate strength capacity of the column strengthened with partial fibers are 13.1% with reference to **A3** as shown in table(5).

Figure(6): : Failure Shape for G1 Control Group.

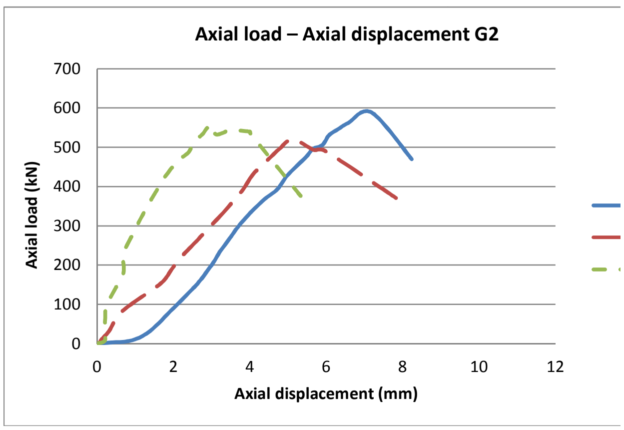
Figure(7): Failure Shape for G2 Basalt Group.

Table (5): Measured loads and strength capacities for tested coulmns

Column	Type of confinement	Ultimate load (kN)	Axial displace ment(m m)	stress at failure (N/mm^2)
A1	----	489.7	6.00	27.59
A2	----	446.4	6.30	25.15
A3	----	473.2	3.77	26.66
B1	Partial basalt	588.2	7.19	33.14
B2	Partial basalt	520.1	5.12	29.30
B3	Partial basalt	535.6	4.01	30.17



Figure(8):Comparison of axial load – axial displacement for tested columns G1.

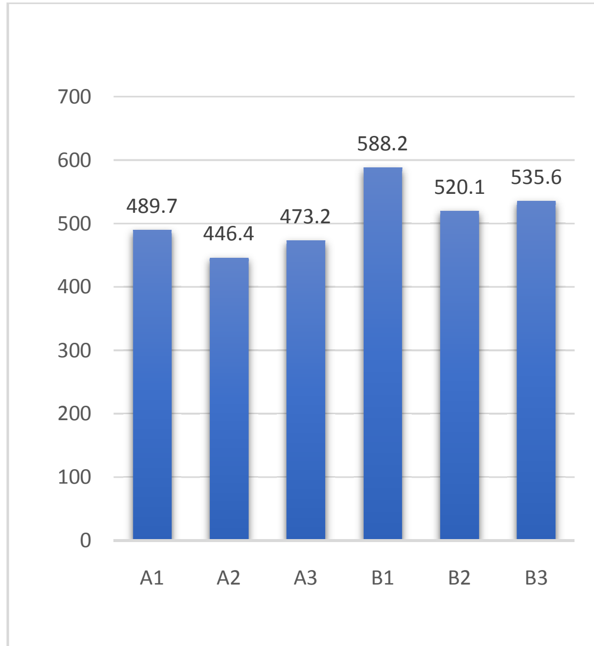


Figure(9):Comparison of axial load – axial displacement for tested columns G2.

CONCLUSIONS

Based on the experimental and analytical studies carried out in this study, the following conclusions can be drawn:

1- All strengthen columns proposed in this study showed general better performance in load capacity, flexibility and energy absorption compared with control columns.
2- For columns the exposure of the concrete surface to 500 C for 1 h directly has effect on the external surface of the specimens and the failure load was reduced compared with the columns which didn't exposed to fire with about 7% in control group and 10% in basalt group respectively.



Figure(10):Comparison of ultimate stress capacity for tested columns

3- Its noticed that using water as cooling method has a positve effect on the ultimate capacity load of column comparing with columns which left to cool down in ambient temperature as shown in columns A3 and B3 which cooled with water compared with A2 and B2 which cooled in ambient temperature about 6.5% increasing in the ultimate load capacity respectively.

4- It is noticed that the value of Vertical strain is inversely proportional to both of the strengthening type of the tested columns and the capacity of the columns, as the strengthening type and capacity of the column increase the value of vertical strain decrease.

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