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The Efficiency of Using Basalt Fibers Sheets for Strengthening of R.C. Columns by Confinement Compared to Carbon and Glass Fiber

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Abstract:

Abstract: Columns are very important structural elements because they are the main supporting elements in RC structures.in some case the desire to change the activity of the concrete structure causes an increase in the loads on the structure. Recently new materials have been developed to enhance the performance of these structural elements. In this research, the square and rectangular concrete columns were strengthened using basalt fibers and compared to glass and carbon fibers.

The practical program was conducted on five column specimen divided into three groups; all specimens have the same height of 1200 mm with different cross sections.

The first group consisted of one specimen with cross section 150 * 150 mm and the specimen had no strength fiber (control specimen)

The second group consisted of two specimens with cross section 150 * 150 mm both specimens were strengthened by basalt fibers the first was partially strengthened using basalt fiber of 100 mm width and the second was fully strengthened.

The third group consisted of two specimens with cross section 150 * 150 mm both specimens were strengthened by glass fibers the first was partially strengthened using basalt fiber of 100 mm width and the second was fully strengthened.

Test results show that confining of the R. C. columns using different Types of strengthening results in significant improvement of the general behavior of the columns. Wrapping using BFRP & GFRP enhances ductility and ultimate strength as well; the theoretical results had been calculated according to the ECP equation and compared to the experimental results. Through the practical study, it is clear that there is an improvement in the column capacity and behavior of all strengthened columns by basalt fiber and glass compared to the unstrengthen columns. The results in this study show that reinforced concrete columns strengthened by glass fiber is more effective by increase the capacity of the column than the basalt fiber.

Keywords **—Basalt Fiber, Glass Fiber, Square columns, Strengthening, FRB**

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I. INTRODUCTION

Columns are very important structural elements because they are the main supporting elements in RC structures. Corrosion of traditional steel causes cracks in columns, which usually leads to failure in critical columns. Nowadays, new materials are developed to enhance the performance of structural elements.

The introduction of fiber-reinforced polymers (FRPs) in civil engineering structures has progressed at a rapid rate in recent years. These high-performance materials that consist of high-strength fibers embedded in a polymer matrix have unique properties, making them extremely attractive for structural applications. FRPs are noncorrosive, have high strength-to-weight ratios, possess good fatigue behavior, and allow easy handling and installation. Moreover, as the fiber types and fiber volumes can be combined in numerous ways, their overall mechanical properties can be tailored to provide optimum solutions to a wide range of structural applications. One area where the use of fiber-reinforced composites has attracted considerable interest is in the strengthening of concrete columns. The confinement of concrete columns is a well-established technique for improving both the compressive behavior and flexural response. With FRP wraps, the confining layer is very thin and is applied directly onto the surface of the column. The composite wraps are flexible and can be handled and cut with little effort.

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.

Basalt fiber (BF) is made of the volcanic basalt ore as raw material through crushing, high temperature melting, drawing to an inorganic fibers material, its appearance is dark brown and color is similar to the carbon fiber. BF completely drew molten by the single basalt ore, comparing to other fiber it has the following features: (1) it has good temperature resistance with an operating temperature range of -269 to 700°C [1-3]. (2) It has good chemical stability and acid/alkali/ corrosion resistant. (3) It has good mechanical properties and higher tensile strength. (4) It is abundantly available and its lower price is about one tenth of the carbon fiber, one sixth to one fourth of the high silicon fiber [4]. (5) It is radiation-resisting and ultraviolet-resisting. (6) It is entirely composed by mineral without adding other ingredients in production and has no harmless for health and environment.

The BF was developed and produced by Former Soviet Union Moscow glass and plastic institute earliest in 1953-1954. In recent years the United States, Japan, Germany and other country have intensified their study of CBF. The research of CBF was developed earliest by Nanjing glass fiber research institutes in the 1990s and focused on military USES. Although the research of CBF start later at home, in some fields it has reached the international leading standard.

In recent years, with the development of the application of BF to structure engineering, national experts mainly research on the mechanical behavior of the basalt fiber concrete and the existing structures reinforcement with BF. Tang Ming et al used the BF as reinforced materials to explore the BF in enhancing effect. They pointed out that the content of BF significant influenced the strength in different ages, and it far outweigh influenced the water-binder ratio and cement-sand ratio. In the field which researched the mechanical characteristics of existing structures reinforced by BF, Wu Gang carried out comparison test under cyclic loading with cylindrical and square columns which reinforced by basalt fiber tow wound and carbon fiber[5]. It was confirmed that using BF reinforced the concrete columns can effectively improve the concrete column’s shear capacity, ductility and energy dissipation. It pointed out that the concrete columns reinforced by basalt fiber tow wound can significantly improve the concrete columns’ shear capacity and changed the specimens’ failure modes. Li Zhiqiang’s study confirmed that using BF reinforced concrete beams can delay the appearance of inclined cracks and constrained the development of inclined cracks by shear reinforcement test. Thus, the beam’s shear capacity, stiffness and deformation capacity can be improved [6]. Six eccentric compression concrete columns strengthened by basalt fiber fabric were tested by Ma Jiansuo. The results showed that both the ultimate bearing capacity and deformation capacity of the eccentric compression column which reinforced by BF has been significantly improved [7]. Sim carried out concrete beams, and compared with the glass fiber reinforced beams under the same conditions. Test results showed that the BF reinforced beams showed better ductility and had obvious signs before destruction [8]. Yang Yongxin performed the beam's bending fatigue performance test, and the results showed that the fatigue performance of the beam have been greatly improved when using BF reinforced. Pasting one layer and two layers of BF, the fatigue life of the reinforced concrete beams were increased by 66% and 23.5%, respectively [9]. When fabric bonded concrete is reliably, the fatigue fracture failure of reinforced concrete beams will likely to occur if the beam's reinforcement ratio less than 2.5.

II. EXPERIMENTAL WORK

The experimental program of the current research consists of three different groups of specimens to study the effect of strengthening on strength and ductility of reinforced concrete square columns. Five R.C. columns with different cross-section, 1200mm (height), with RFT details as shown in figure (1).

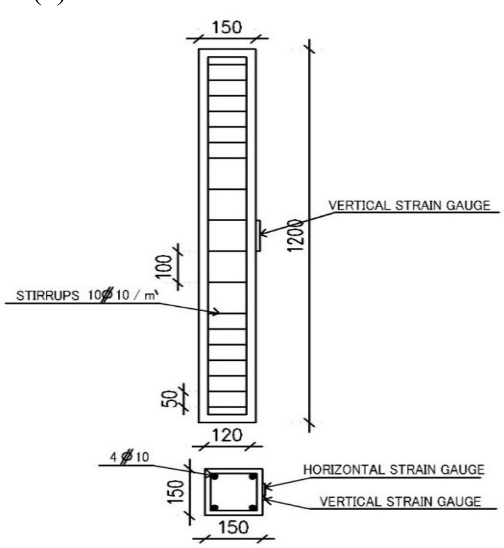

Fig. 1 Details of Typical Specimen

Two parameters were considered in this study; Control,and StrengtheningMaterial. Details of tested specimens with different parameters are shown in table (I).

TABLE I
EXPERIMENTAL PROGRAM

Group NO.	Column NO.	Geometry (mm)	Area Steel	Stirrups	Strengthening Material	Strengthening Shape	Spacing (S) (mm)	Parameter Study
1	C1	150x150	4 Ø 10	10 Ø 8/m	——	——	——	Control
2	C2	150x150	4 Ø 10	10 Ø 8/m	Basalt Fiber	Partial	S = 80	Strengthening Material
	C3	150x150	4 Ø 10	10 Ø 8/m		Total	——	
3	C4	150x150	4 Ø 10	10 Ø 8/m	Glass Fiber	Partial	S = 80	Strengthening Material
	C5	150x150	4 Ø 10	10 Ø 8/m		Total	——	

C= Column Axial (Short Column L = 1200 mm

The experimental work has been planned to investigate the difference in global behavior between conventional reference short rectangular columns constructed of normal strength concrete and those columns strengthened with different types of strengthening such as:

1. Basalt fiber strengthening.
2. Glass fiber strengthening.

The test measurements include the first crack loads, failure loads, crack patterns, axial deformations, and concrete strains.

Therefore, a total of Five columns classified into three groups as shown in Table (1).

The first group consists of one columns designated by C1 Where C1 represents the behavior of control column reference specimens without any strengthening.

The second group represents the Strengthening using Basalt Fiber which consists of two columns designated by C2 and C3.

Where:

C2: Is strengthened with a Partial layer of Basalt Fiber consists of 100mm width, spacing of 80mm and Dimension of 150X150 mm.

C3: Is strengthened with one layers of Basalt Fiber for the full height of 1200 mm and with dimension 150X150 mm and with Fiber overlap of 100mm.

The third group represents the Strengthening using Glass Fiber which consists of two columns designated by C4 and C5:

Where:

C4: Is strengthened with a Partial layer of Glass Fiber consists of 100mm width, spacing of 80mm and Dimension of 150X150 mm.

C5: Is strengthened with one layers of Glass Fiber for the full height of 1200 mm and with dimension 150X150 mm and with Fiber overlap of 100mm.

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

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

For the specimens with cross section 150 X 150 Each column is reinforced with 4Ø10 mm longitudinal reinforcing plain bars providing reinforcement ratio of 1.4%.. For all columns, tied stirrups were provided of Ø8 mm bars. Pitches of stirrups were 50 mm at the column ends and 100 mm along column height. Whereas the stirrups are concentrated at the column ends to avoid local failure at the column ends due to stress concentration.

The electrical strain gauges are used to measure different strains of the columns. One strain gauge is used for each specimen to measure vertical strain of concrete and the second strain gauge to measure the horizontal strain of concrete , the location of both strain gauges at the mid height 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 .

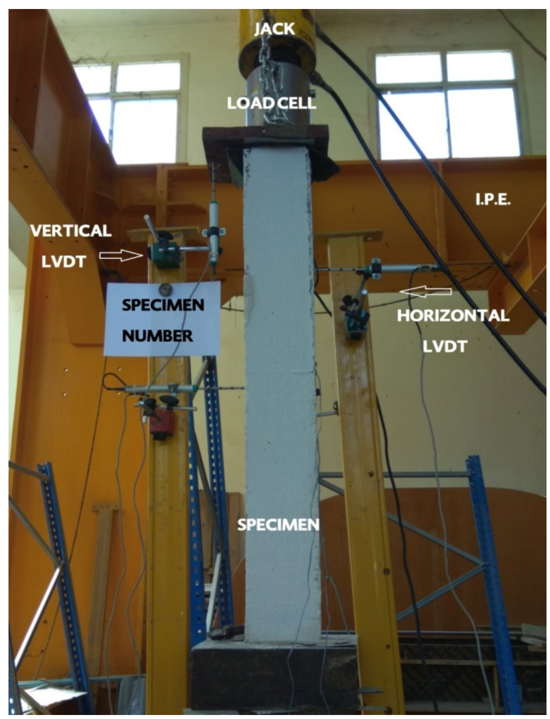

Fig. 2 Test Setup

III. 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, ultimate load and vertical strain.

1. Ultimate loads and strength

TABLE IIIII
SHOWS THE TOTAL NO. OF SPECIMENS AND THE DIFFERENT PARAMETER ALSO IT SHOWS THE TOTAL RESULTS FOR THE TESTED SPECIMENS.

Column	Type of confinement	Ultimate load (kN)	stress at failure (N/mm^2)	Vertical strain ($*10^{-3}$)	Horizontal strain ($*10^{-3}$)
C1	Control 150x150	697	30.9	0.88	0.0914
C2	Partial basalt 150x150	728	32.3	0.861	0.142
C3	Total basalt 150x150	752	34.4	0.7	0.24
C4	Partial Glass 150x150	780	34.6	0.715	0.152
C5	Total Glass 150x150	870	38.6	0.88	0.175

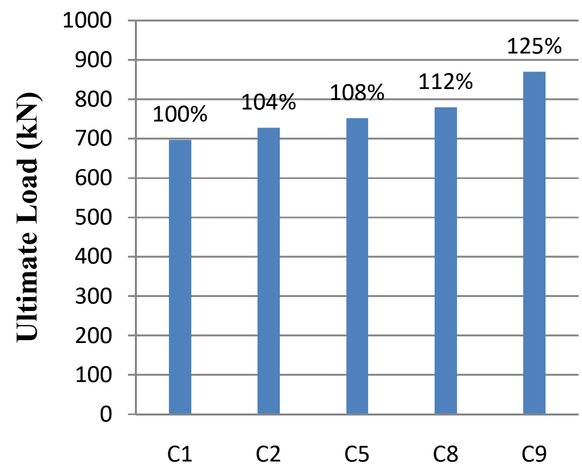

Fig. 3Comparison of ultimate stress capacity for tested columns

2. The Effect of Basalt Fiber strengthening on the Square column Compared to Glass Fibers:

This part presents the effect of the type of the fiber sheets whether partial confinement or full confinement on square columns, a comparison between different results of basalt and glass, fibers has been shown.

2.1 Total Strengthening:

TABLE IVV
RESULTS FOR TESTED COLUMNS

Column	Type of confinement	Vertical strain (*10-3)	Horizontal strain (*10-3)
C1	Control 150x150	0.88	0.0914
C3	Total basalt 150x150	0.7	0.24
C5	Total Glass 150x150	0.65	0.175

2.1.1 Crack Pattern for partial strengthening specimens:

From the observed crack pattern figures it is noticed that the behavior of the total confinement of carbon, glass and basalt fibers are all the same behavior as they have cracks appear vertical and starting to propagate from upper third as shown in Figure (4).

Due to cutting of the FRP wraps in the three specimens a failure in the specimens happened so crack pattern can be classified as crushing failure.

Fig. 4 Failure shape for glass and basalt fibers.

2.1.2 Load –Vertical strain curves for total strengthening specimens:

Figure 5 show a comparison between load – vertical strain for specimen C3 (150X150) total basalt, C5and (150x150) total glass which represent decrease in the vertical strain by 20.4 %, 35.4%, respectively with reference to C1.

It also shows that the enhancement in the ultimate strength capacity of the columns strengthened with partial fibers are 8%, and 25%, respectively with reference to C1 as shown in Figure 5.

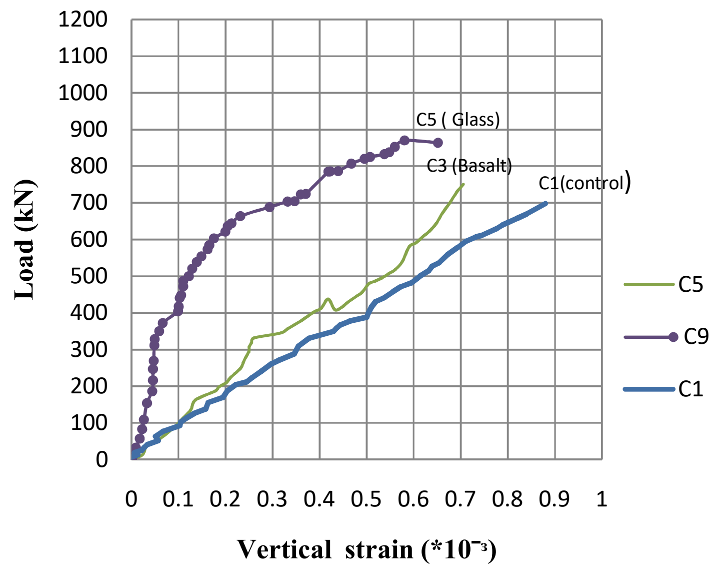

Fig. 5 load –Vertical strain curve for total strengthening group.

2.2 Partial Strengthening:

TABLE V
RESULTS FOR TESTED COLUMNS

Column	Type of confinement	Vertical strain (*10-3)	Horizontal strain (*10-3)
C1	Control 150x150	0.88	0.0914
C2	Partial basalt 150x150	0.861	0.142
C4	Partial Glass 150x150	0.715	0.152

2.2.1 Crack Pattern for partial strengthening specimens:

From the observed crack pattern figures it is noticed that the behavior of partial basalt confinement fiber is close to the behavior of the carbon fiber as it both have cracks appear vertical and starting to propagate from upper third on the other side the glass fiber only has vertical cracks in the fiber and the concrete as shown in Figure (6).

Due to cutting of the FRP wraps in the three specimens a failure in the specimens happened so crack pattern can be classified as crushing failure.

Fig. 6 Failure shape for glass and basalt fibers.

2.2.2 Load –Vertical strain curves for total strengthening specimens:

Figure 7 show a comparison between load – vertical strain for specimen C2 (150X150) partial basalt, C4 (150x150) partial glass, which represent the enhancement in the ultimate strength capacity of the columns strengthened with partial fibers are 4 % and 12%, respectively with reference to C1.It also represents a decrease in the vertical strain by 2.15% and 19.3% respectively with reference to C1.

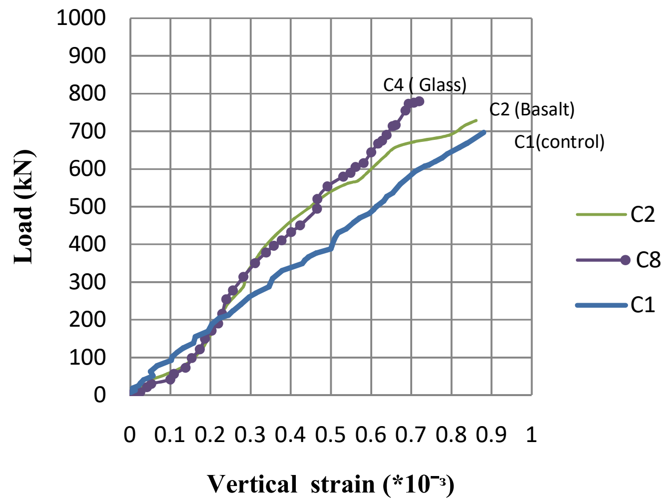

Fig. 7 load –Vertical strain curve for total strengthening group.

IV. 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.

2- In spite of the increase in the capacity of partial Basalt confined square column , but by comparing it to the partial Glass confined square column it shows that Glass fiber strengthening is more effective than the basalt fiber as the Glass fiber increase the capacity of the column with 12 % while the basalt fiber increase the capacity of column by 4 %with reference to C1 .

3- In spite of the increase in the capacity of Total Basalt confined square column, but by comparing it to the Total Glass confined square column it shows that Glass fiber strengthening is more effective than the basalt fiber as the Glass fiber increase the capacity of the column with 25 % while the basalt fiber increase the capacity of column by 8 % with reference to C1.

4- It is noticed that the value of Horizontal strain is directly 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 increase.

5- 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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