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SPRAYED TEXTILE REINFORCED GFRC FOR RETROFITTING OF SUB-STANDARD NON-CIRCULAR CONCRETE COLUMNS

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Abstract

In this study, effectiveness of a new type of retrofitting method on the axial performance of low strength columns is investigated. In this method, sprayed glass fiber reinforced concrete (GFRC) with basalt textile reinforcement is used for external confinement of columns. Four reference and eight retrofitted specimens with square (200x200 mm) or rectangular (200x300 mm) cross sections were tested under monotonic axial loading. Test results showed that the proposed retrofitting technique is quite promising for retrofitting of low strength concrete members in terms of strength, and particularly deformability. The enhancement of strength and deformability is also predicted analitically based on the concept of effectively confined section geometry and it is shown that the experimental results and analytical predictions are in a good agreement. Consequently, this type of retrofitting can be considered for stregth and deformability enhancement of sub-standard reinforced concrete columns in seismic prone areas.

Keywords: basalt textile; low strength concrete; retrofit; deformability; sprayed glass fiber reinforced concrete

1. Introduction

Many existing reinforced concrete buildings suffer from brittle behavior of reinforced concrete columns arising from low strength concrete and/or inadequate transverse reinforcement during earthquakes. To prevent severe structural damage and life losses during earthquakes, this type of columns should be retrofitted to ensure satisfactory strength and ductility. One possible method to improve these characteristics of deficient structural members is external confinement. Among these confinement methods, external confinement using Fiber Reinforced Polymers (FRPs) has gained an advantage over traditional techniques due to profitable properties as high strength to weight ratio, ease of implementation and minimal geometry change after application. Besides all these favorable properties, FRPs has also some drawbacks as high initial cost, loss of strength above glass transition temperature, incompatibility with concrete, difficulty of conducting post-earthquake assessment and harmful gas emission during application. To overcome these deficiencies, cementitious mortars can be used instead of resins. Such systems are generally named in literature as Textile Reinforced Mortars (TRM). Recent researches have shown that usage of TRM is a promising retrofitting solution for reinforced concrete and masonry members [1-5].

In this study, glass fiber reinforced concrete (GFRC) and basalt textiles were used for retrofitting of sub-standard concrete columns. Basalt textiles had a mesh geometry. Unlike traditional application of matrix material to the surface e.g. with metal trowel, spraying method was used during the application of GFRC to the surface of the columns. While spraying the GFRC to the surface, an automated mixture machine and a spraying gun were used. By the use of spraying method, application of retrofitting process became much quicker when compared to traditional application of TRM. Additionally, usage of glass fibers improved the tensile characteristics of matrix material. Due to higher tensile strength of GFRC, relatively better performance is expected than standard cement based matrices [6,7].

2. Experimental Study

A total of twelve specimens with square and rectangular cross-sections (200 mm x 200 mm and 200 mm x 300 mm) with the height of 500 mm were tested under monotonic axial loading. Four of specimens were reference specimens while remaining specimens were retrofitted using basalt textile reinforced sprayed GFRC. Numbers of basalt textile reinforcement layers varied from 1 to 3. A photo of basalt textile reinforcement used in this study is given in Fig.1.

Specimens were denoted in the form of X-YZ. X is used for the section type (S for square, R for rectangular), Y stands for the number of basalt textile reinforcing layers embedded into GFRC (varied from 1 to 3 and REF for reference specimens). Finally Z is used for distinguishing the specimens with same configuration. Details and notations of tested specimens are shown in Table 1.

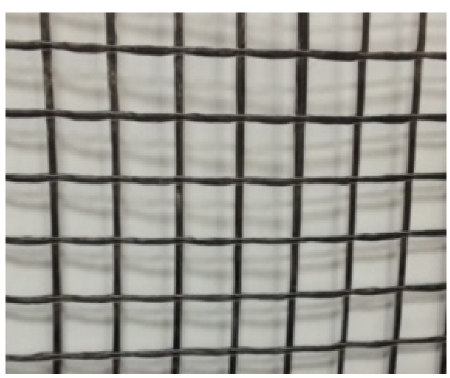


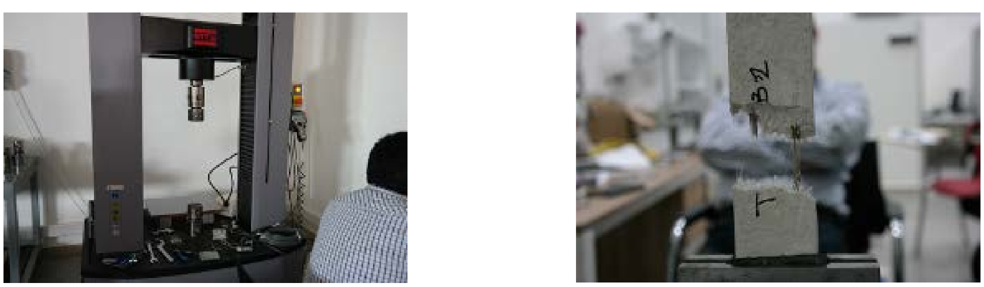
Fig. 1 – A photo of basalt textile reinforcement

Table 1 – Details and notations of tested specimens

Notation	Cross-Section (mmxmm)	Retrofitting procedure	Jacket thickness (mm)
S-REFa	200x200	-	-
S- REFb	200x200	-	-
S-1a	200x200	GFRC + 1 layer of basalt reinforcement	25
S-1b	200x200	GFRC + 1 layer of basalt reinforcement	25
S-2	200x200	GFRC + 2 layers of basalt reinforcement	25
S-3	200x200	GFRC + 3 layers of basalt reinforcement	25
R-REFa	200x300	-	-
R-REFb	200x300	-	-
R-1	200x300	GFRC + 1 layer of basalt reinforcement	25
R-2	200x300	GFRC + 2 layers of basalt reinforcement	25
R-3a	200x300	GFRC + 3 layers of basalt reinforcement	25
R-3b	200x300	GFRC + 3 layers of basalt reinforcement	25

2.1 Material Properties, Retrofitting Procedure and Test Setup

All specimens were cast using a single batch of ready-mixed concrete. For representing concrete quality of existing buildings, all specimens were constructed using low strength concrete. 180 days average compressive strength of standard cylinder specimens was approximately 10 MPa. Concrete mixture proportions are given in Table 2. The mixture of GFRC mortar consists of standard white Portland cement (45 kg/50 dm3), fine silica sand (50 kg/50 dm3), mineral admixture (5 kg/50 dm3), polymer (1.65 kg/50 dm3), water (16 kg/50 dm3) and plasticizer (0.12 kg/50 dm3). Ultimate tensile strengths obtained with uniaxial tensile coupon tests for the combinations of GFRC with 1 layer of basalt textile reinforcement and GFRC with 2 layers of basalt textile reinforcement were 7.5 MPa and 9 MPa, respectively. For the combination of GFRC with 3 layers of basalt textile reinforcement direct tensile strength was obtained as 11 MPa. MTS tensile test machine was used during direct tensile tests and two representative specimens for each jacketing type were tested. An image of the test machine and the specimen GFRC with 2 layers of basalt textile reinforcement after testing are given in Fig. 2 (a) and Fig. 2 (b), respectively.



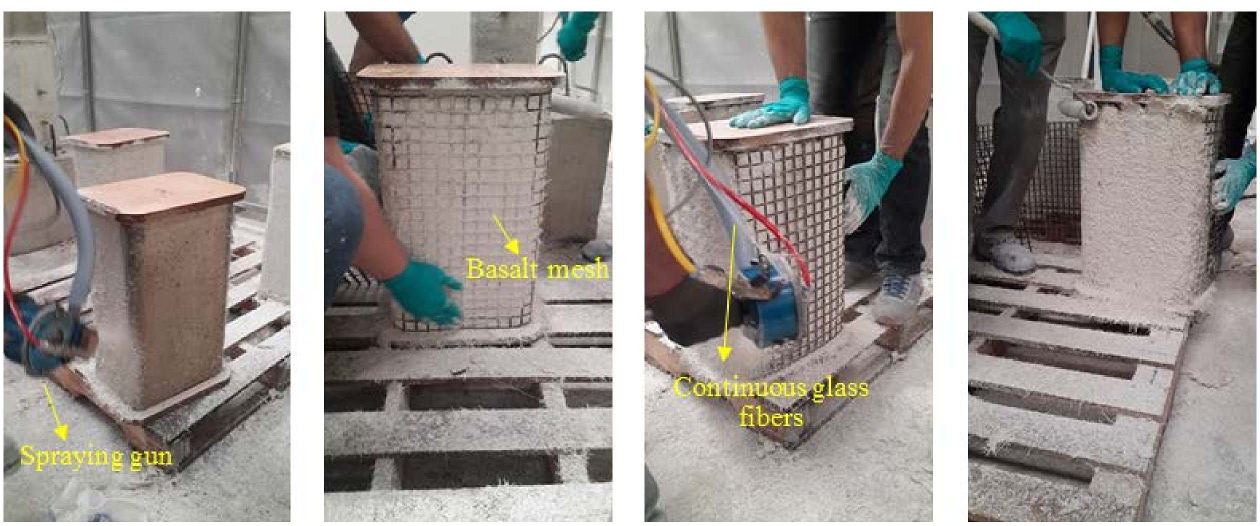
(a) (b)

Fig. 2 – A photo of (a) direct tensile test machine and (b) specimen GFRC with 2 layers of basalt textile reinforcement after testing

Table 2 – Concrete mixture proportions

Material	kg/m^3
Portland Cement	215
No.1 Crushed Aggregate	923
Sand	1104
Superplasticizer	2.75
Water	232

Specimens except reference ones were retrofitted with external jacketing using sprayed GFRC with one, two or three layers of basalt textile reinforcement. Sprayed GFRC contains chopped randomly oriented and distributed alkali resistant glass discrete fibers with a length of 24 mm. Chopping of continuous glass fibers and spraying of glass fiber reinforced concrete processes were done simultaneously by using a spraying gun. Main steps of retrofitting procedure for the specimens retrofitted with sprayed GFRC and basalt textile reinforcement were: (i) rounding of corners to radius of 30 mm to prevent stress concentrations around the corners of jacketing material, (ii) surface preparations and saturating of concrete surface with water, (iii) spraying of the first layer GFRC to specimen's surface, (vi) wrapping and embedding of the first basalt textile reinforcement layer into GFRC, (v) covering of first basalt textile reinforcement layer with sprayed GFRC. Steps (iv) and (v) were continued until the desired number of layers of basalt textile reinforcement was applied. Basalt textile reinforcement was continuously wrapped for the jackets that contained more than one layer of basalt textile reinforcement. It should be noted that at least 5 mm thick GFRC was sprayed between each basalt layer. Total thickness of sprayed external jacket was 25 mm for all specimens. In order to avoid direct axial loading of the external jacket during loading, retrofitting jacket was not continued along the full length of specimen and a gap of 20 mm was left at the top and bottom of the specimen. Application steps of retrofitting are shown in Fig. 3. Mechanical properties of GFRC at the age of 28 days are given in Table 3 while the mechanical properties of and basalt textile reinforcement and glass discrete fibers provided by the manufacturers are given in Table 4 and Table 5, respectively.



(a) (b) (c) (d)

Fig. 3 – Retrofitting process; a) application of first layer GFRC to the concrete surface, b) embedding of basalt textile reinforcement into the GFRC, c) covering of basalt textile reinforcement with GFRC, d) finishing of application

Table 3 – Mechanical properties of GFRC

Compressive Strength (MPa)	**Flexural Strength** (MPa)	**Fiber Ratio** (% by weight)	**Fiber Length** (mm)
43.5	15	3.5	24

Table 4 – Mechanical properties of basalt textile reinforcement

Elasticity Modulus (GPa)	**Mesh Size** (mm x mm)	**Tensile Strength** (MPa)	**Strain at Breaking**
32	25 x 25	1600	0.05

Table 5 – Mechanical properties of glass discrete fibers

Elasticity Modulus (GPa)	**Length** (mm)	**Tensile Strength** (MPa)
72	24	1700

All specimens were tested under monotonic uniaxial compression. Tests were performed by using an Amsler hydraulic testing machine with a capacity of 5000 kN. Linear Variable Displacement Transducers (LVDT) with two different gage lengths as 250 mm and 500 mm were used to measure average axial strains. While LVDTs with 500 mm gage length were placed between top and bottom plates of the loading system on four corners, 250 mm gage length LVDTs were placed at mid-height on the rods which were anchored to drilled holes in the jacket and concrete. In this study, data obtained in 500 mm gage length were used because the rods on which 250 mm transducers were attached rotated due to different shortening of the core and jacket parts of the specimens. In addition to LVDTs, four straingages were adhered to mid-height of specimens at each side to measure the lateral strains on retrofitting jacket. Before testing, top and bottom surfaces of the specimens were capped using high strength mortar. Moreover, grease oil was applied between loading caps and loading plates to minimize the friction. Test setup is shown in Fig. 4.

Fig. 4 – Test setup

2.2 Test Results

Test results are given in Table 6. Test results are evaluated according to gain in compressive strength and deformability factors. Gain in compressive strength is defined as the ratio of compressive strength of retrofitted specimen to that of reference specimen (f_{cc}/f_{c0}). Deformability factor is calculated as the ratio of strain values corresponding to 85% of peak stress on the descending branch of stress-strain curve to the strain value corresponding to unconfined concrete compressive strength ($\varepsilon_{cu,0.85}/\varepsilon_{c0}$). ε_{c0} is assumed as 0.002 as commonly done in similar studies [8,9].

As it can be clearly seen in Table 6, significant gain in compressive strength and deformability are achieved for all retrofitted specimens. As expected, when compared to square specimens, enhancement in compressive strength is less notable for the rectangular specimens. On the other hand a specific trend is not found between number of basalt reinforcement layers and gain in compressive strength. Although direct tensile strength of GFRC with 2 layers of basalt textile reinforcement coupon specimens are notably higher than GFRC with 1 layer of basalt textile reinforcement coupon specimens, strength and deformability enhancement of the specimens retrofitted with these two combinations are not distinctly different from each other. This is attributed to the dual contribution of GFRC and basalt textile reinforcement, and potential non-uniform distribution of glass fibers within GFRC matrix.

Damage patterns were similar for all retrofitted specimens. Generally one vertical crack or two symmetrical vertical cracks at opposite faces formed when the specimen reached its ultimate strength. The locations of cracks were close to corners. Specimens finally failed by the rupture of basalt textile reinforcement with a substantial loss in strength. Damage photos of S-1a and R-3a after testing are given in Fig. 5.

Table 6 – Test results

Specimen	**f_{c0} (MPa)**	**f_{cc} (MPa)**	**$\varepsilon_{cu,0.85}$** [b]	**$\varepsilon_{cu,0.85}/\varepsilon_{c0}$**	**f_{cc}/f_{c0}**	**$\dfrac{\varepsilon_{cu,0.85} / \varepsilon_{c0} \text{ (retrofitted)}}{\varepsilon_{cu,0.85} / \varepsilon_{c0} \text{ (reference)}}$**
S-REF[a]	8.49	-	0.0044	2.2	1	1
S-1[a]	-	13.46	0.0067	3.35	1.59	1.52
S-2	-	13.80	0.0066	3.30	1.63	1.5
S-3	-	14.65	0.0077	3.85	1.73	1.75
R-REF[a]	9.63	-	0.0040	2	1	1
R-1	-	12.73	0.0049	2.45	1.32	1.23
R-2	-	12.33	0.0049	2.45	1.28	1.23
R-3[a]	-	12.61	0.0069	3.45	1.31	1.73

Note: [a]Average results of two identical specimens

[b] $\varepsilon_{cu,0.85}$ values are obtained by assuming the strain corresponding to peak stress equal to 0.002

(a) (b)

Fig. 5 – Damage photos of a) S-1a, b) R-3a after testing

3. Analytical Predictions

In this part, an analytical model is proposed for predicting the peak stresses (f_{cc}) and strain values corresponding to 85% of peak stress ($\varepsilon_{cu,0.85}$) on the descending branch of stress-strain relationship for retrofitted specimens with proposed retrofitting method. For analytical predictions of f_{cc} and $\varepsilon_{cu,0.85}$, a general confinement model suggested by Triantafillou et al. [1] is used after modifying slightly to consider the difference between ε_{c0} and $\varepsilon_{cu,0.85}$ through the coefficient k_2, Eq. (1) and Eq. (2).

$$f_{cc} = f_{c0} + k_1\sigma_{lu} \tag{1}$$

$$\varepsilon_{cu,0.85} = k_2\varepsilon_{c0} + k_3\left(\frac{\sigma_{lu}}{f_{c0}}\right) \tag{2}$$

where; f_{c0} is the ultimate compressive strength of unconfined reference specimen, ε_{c0} is the strain value corresponding to ultimate compressive strength of unconfined concrete and assumed as equal to 0.002, k_1, k_2 and k_3 are empirical constants, σ_{lu} is the confining pressure and can be calculated using Eq. (3)

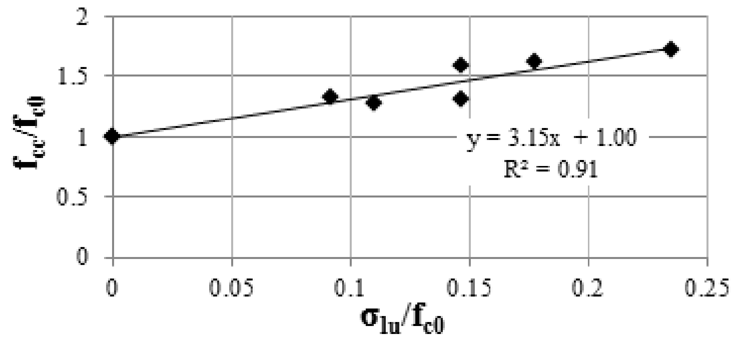
$$\sigma_{lu} = k_e\frac{(b+h)}{bh}tf_t \tag{3}$$

$$k_e = 1 - \frac{\left((b-2R_c)^2 + (h-2R_c)^2\right)}{3A_g} \tag{4}$$

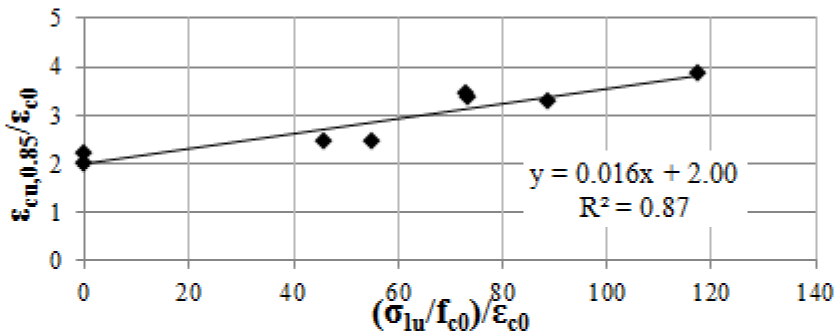
In Eqs. (3) and (4) f_t is the tensile strength of jacketing material obtained from direct tensile test, t is the thickness of the jacket, b and h are the width and length of specimens, R_c is the corner radius and A_g is the total cross-sectional area of the column, Eq. (5).

$$A_g = bh - (4-\pi)R_c^{\,2} \tag{5}$$

For determining the empirical constants, k_1, k_2 and k_3, a linear regression analysis is carried out considering the test results shown in Fig. 6. Based on the satisfactory agreement of regression results, the values of k_1, k_2 and k_3 are obtained as 3.15, 2.0 and 0.016, respectively. As expected and presented in Table 7, the experimental results and analytical predictions are in a good agreement.



(a)



(b)

Fig. 6 – Regression models for determining a) k_1, b) k_2 and k_3

Table 7 – Comparison of analytical predictions and experimental values

Specimen	Experimental		Analytical		$\frac{f_{cc,experimental}}{f_{cc,analytical}}$	$\frac{\varepsilon_{cu,0.85\ experimantal}}{\varepsilon_{cu,0.85\ analytical}}$
	f_{cc} (MPa)	$\varepsilon_{cu,0.85}$	f_{cc} (MPa)	$\varepsilon_{cu,0.85}$		
S-REF[a]	8.49	0.0044	8.49	0.0040	1.00	1.1
S-1[a]	13.46	0.0067	12.46	0.0064	1.08	1.05
S-2	13.80	0.0066	13.28	0.0068	1.04	0.97
S-3	14.65	0.0077	14.84	0.0078	0.99	0.99
R-REF[a]	9.63	0.0040	9.63	0.0040	1.00	1.00
R-1	12.73	0.0049	12.43	0.0055	1.02	0.89
R-2	12.33	0.0049	13.01	0.0056	0.95	0.88
R-3[a]	12.61	0.0069	14.11	0.0063	0.89	1.10
				Average	1.00	1.00
				S.Deviation	0.057	0.084

Note: [a] Average results of two identical specimens

4. Conclusions

In this study, the contribution of external jacketing with basalt textile reinforced sprayed GFRC on the axial performance of low strength columns with square (200x200 mm) or rectangular (200x300 mm) cross sections was investigated. After uniaxial compression tests, the following results were obtained.

Basalt textile reinforced sprayed GFRC for external confinement of low strength concrete members is a suitable strengthening technique due to the enhancement observed in compressive strength and deformability.

For the specimens with rectangular cross-section, as the ratio of cross-sectional aspect ratio (h/b) increases the confinement effectiveness reduces.

Considering the ease and prompt implementation, relatively low cost and renewability, presented retrofitting method is an alternative to conventional retrofitting methods.

A simple analytical model is presented for predicting ultimate strength and strain values corresponding to 85% of peak stress on the descending branch of axial stress-strain relationship.

The results presented in this paper are based on a limited number of test specimens. Therefore, further studies are required to better determine effectiveness of the proposed method for confinement of structural members.

5. Acknowledgement

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