Concrete Cylinders Confined with Basalt Fibre Reinforced Polymer


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ABSTRACT

Concrete columns have an important function in many structures and can be vulnerable to exceptional loads. In older structures, columns often have a lack of transverse reinforcement, which is unable to provide sufficient confinement to the concrete core or to prevent buckling of the longitudinal reinforcement which causes premature strength degradation of the column. This paper presents a test program that was done on concrete cylinders confined with basalt fibre reinforced polymer (BFRP) and examination of its tensile strength. The test results show that the strength enhancement of the concrete cylinders consists of more ductile behaviour.

Key words: Concrete, confinement, basalt, BFRP and strengthening.

1 INTRODUCTION

The wrapping of FRP composite sheets around concrete columns is a promising method for structural strengthening and repair for their unique properties in terms of strength, lightness, chemical resistance and ease of application. This strengthening technique is of practical interest for their fast execution and low labour cost. The sheets provide a passive confinement to the concrete core and react against the lateral dilation of the column under compression, which delays the softening of the concrete and has shown to enhance both strength and ductility of the column [1]. Extensive work has been done in the experimental and analytical areas on concrete specimens of circular columns since the development of FRP wrapping started in the 1980s and later on, columns of square and rectangular cross sections [2-6]. e experimental work have mostly focused on the common FRP materials on the market which are carbon(CFRP), glass(GFRP) and aramid(AFRP) fibre. BFRP is a new material in civil engineering compared to carbon, glass and aramid and has shown to be a promising material for infrastructure strengthening. They are made from basalt rocks through melting process and contain no other additives in the producing process which makes advantages in cost. Basalt fibres show comparable mechanical properties to glass fibres at lower cost and exhibit good resistance to chemical and high temperature exposure [5]. The ultimate strain of BFRP is higher compared to other common FRP materials and thus it is interesting to use this advantage in column strengthening to enhance the seismic performance. There is little research concerning the application of basalt fibre in civil engineering and its strengthening efficiency on concrete elements. This paper presents the tests that were performed on BFRP tensile coupon specimens and concrete cylinders confined with BFRP under concentric compression loading.

2 Experimental Program

2.1 Tensile Coupon Tests

Tensile coupon tests were made on five specimens to determine the actual material strength of the BFRP composite. The BFRP was formed from unidirectional woven basalt sheet and epoxy resin. The basalt sheet had a nominal thickness of 0,65 mm, which was used for the calculation of material properties. The dimensions of the tensile specimens were determined according to the ASTM standard recommendations [7].

A single layer of BFRP tensile specimen was prepared and tested of 25 mm width and 250 mm length. Each end had an additional layer on each side for more strength at the gripping zone. The preparation started with the usual wet layup process involving the impregnation of each basalt sheet with epoxy resin, followed by the application of an additional layer of sheet at each end. All the specimens were allowed to cure at room temperature for seven days before testing. All specimens were tested in a testing machine with a load capacity of 100 kN at a head displacement rate of 2 mm/min according to ASTM [7]. The longitudinal strains were measured simultaneously using two strain gages at opposite sides of the specimens with an active gage length of 6 mm. In the results, the strains are the average from the two strain gages. Two computers were used for data reading, one for the load reading and one for the strain reading.

2.2 Compression Tests on BFRP Confined Cylinders

Total of 12, 100mm x 200mm concrete cylinders, were casted with a concrete of 25 MPa compressive strength supplied by a local concrete manufacturer. To examine the confinement stiffness variation, the specimens were wrapped with one, two and three number of layers where one basalt sheet refers to one layer of BFRP jacket. Three cylinders were without jackets for examining the unconfined concrete strength. Three identical cylinder specimens were made for each number of BFRP layers.

After casting, the cylinders were let to cure in a humidity room for 14 days before they were prepared for wrapping. Before the wrapping procedure began, the concrete surface of the cylinders was wired brushed to remove loosely held powders and cleaned with compressed air and water and left to dry. The fabric sheets were cut with lengths of 0,46 m for one layer, 0,78 m for two layers and 1,09 m for three layers. The width was cut to 0,19 m, which provided 5 mm gap on each end of the cylinder to prevent axial load on the BFRP jacket. As the sheets were wrapped in a continuous way, these lengths allowed for an overlap of 150 mm. All cylinders were wrapped according to the wet layup process and cured at room temperature for seven days before testing. All specimens were axially loaded in a universal testing machine with a compressive capacity of 2500 kN under displacement control mode with a constant speed of

0,5 MPa/s. Axial load was recorded from on output signal from the test machine and the axial deformation was measured as the displacement of the loading base plate.

3 Test Results

3.1 Tensile coupon test specimens

All specimens showed a good linear response up to first failure at peak load. There the applied stress decreased when the fibre at the edge ruptured and then started to increase again until the whole section ruptured. Table 1 presents the test results from each specimen where F is the applied tensile force, σ is the tensile stress obtained from the tensile force and the cross section area, ε is the longitudinal strain measured by the strain gauges and E is the elastic modulus calculated according to ASTM [37].

Table 1 – Tensile coupon test results.

Specimen	F (kN)	σ (MPa)	ε (%)	E (GPa)
BU-1	11,99	780,58	2,53	31,059
BU-2	12,27	807,62	2,91	27,607
BU-3	11,44	732,57	2,84	31,489
BU-4	11,15	748,20	2,72	24,585
BU-5	11,66	732,71	2,56	29,613
Average	11,70	760,34	2,71	28,871

3.2 Cylinder specimens

Distinct hardening response was observed in all specimens after reaching the unconfined concrete strength where the BFRP jacket activates. The failure of the specimens can be divided into two modes, tensile rupture of the BFRP jacket and a combination of delimination at the overlap and tensile rupture of the BFRP jacket. Table 2 presents the average test results from each cylinder series where n is the number of layers, f_c is the unconfined concrete strength obtained from the plain cylinders, f_{cc} is the confined compressive strength, ε_{c1} is the axial strain corresponding to the unconfined concrete strength and ε_{cu} is the ultimate axial strain at failure. In figure 2 cylinders are shown before and after failure of the BFRP jacket.

Table 2 – Compression test results.

Specimen	n	f_c (Mpa)	f_{cc} (Mpa)	f_{cc}/f_c	ε_{c1} (%)	ε_{cu} (%)	$\varepsilon_{cu}/\varepsilon_{c1}$
SBU1	1	35,80	54,67	1,53	0,40	2,81	7,05
SBU2	2	35,80	79,34	2,22	0,40	4,01	10,09
SBU3	3	35,80	104,06	2,91	0,40	5,06	12,72

4 Discussion

Where the fibres ruptured first at the edges on the tensile coupon specimens indicates that the orientation of the fibre to the applied tensile load was not perfectly parallel which however can be the case in structural strengthening. Therefore, the ultimate strength and strain were taken at the peak load which was considered to represent the material strength of the BFRP jacket. Figure 1 shows very well the increase in compressive strength and axial strain obtained by adding additional BFRP layer on the concrete cylinders. All cylinders show a good ductile behaviour where the maximum gain in axial strain is 12,7 times the unconfined peak strain and corresponding gain in compressive stress is 2,9 times the unconfined concrete strength. These results review the efficiency of BFRP as a strengthening material for concrete columns but as this paper only presents tests on small concrete specimens, further research needs to be done on reinforced columns of different cross sections.

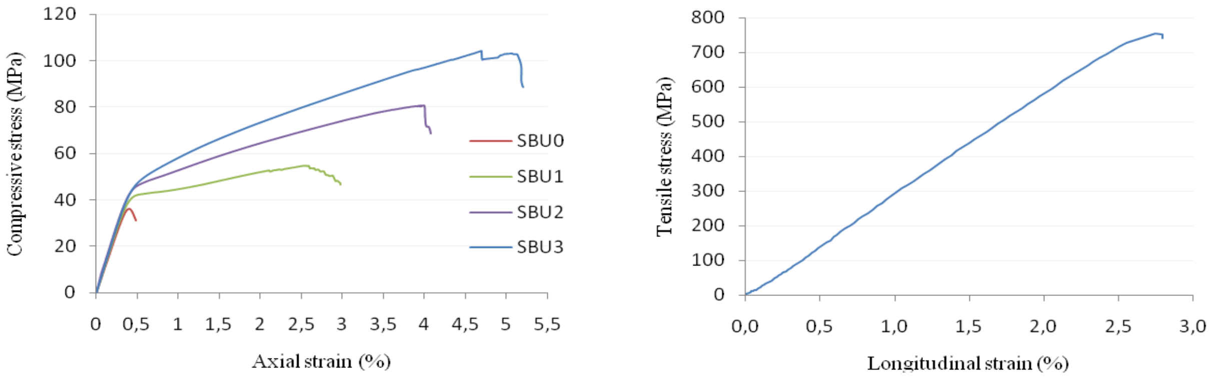

Figure 1 - Left: Average stress strain curves for cylinder specimens. Right: Average stress strain curve for BFRP.

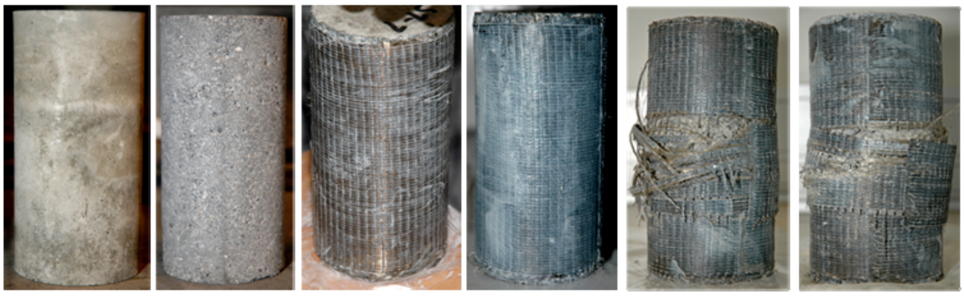

Figure 2 - Test procedure on cylinders from being removed from humidity room to failure of BFRP jacket.

REFERENCES

[1] A. Nanni and N. M. Bradford, "FRP jacketed concrete under uniaxial compression," *Construction and Building Materials,* vol. 9, pp. 115-124, 1995.

[2] M. J. N. Priestley*, et al.*, *Seismic design and retrofit of bridges*. New York: John Wiley & Sons, Inc., 1996.

[3] H. Saadatmanesh, *et al.*, "Strength and Ductility of Concrete Columns Externally Reinforced With Fiber Composite Straps," *ACI Structural Journal,* vol. 91, pp. 434-447, 1994.

[4] M. Demers and K. W. Neale, "Confinement of reinforced concrete columns with fibre-reinforced composite sheets-an experimental study," *Canadian Journal of Civil Engineering.,* vol. 26, pp. 226-241, 1999.

[5] S. Matthys*, et al.*, "Axial Load Behavior of Large-Scale Columns Confined with Fiber-Reinforced Polymer Composites," *ACI Structural Journal,* vol. 102, p. 258, 2005.

[6] F. Michael N and K. Homayoun, "Concrete Encased in Fiberglass-Reinforced Plastic," *ACI Structural Journal,* vol. 78, pp. 440-446, 1981.

[7] ASTM, "Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials," American Society for Testing and Materials, West Conshohocken, USA,2008.