Effects of GFF Bands on Normal and High Strength Concrete Cylinders

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Abstract

This paper exemplifies the effects of externally confined Glass Fibre Fabric (GFF) bands on normal and high strength concrete cylinders. Twelve normal and high strength concrete cylinders were cast and tested in the laboratory environment under axial compression to failure. The experimental results show that the degree of confinement of discrete GFF confined high strength concrete cylinders was significantly better than normal strength concrete cylinders with GFF bands, however the ductility of GFF confined high strength concrete cylinders was relatively less than GFF normal strength concrete. It was also found that the application of horizontally oriented GFF bands is the most effective confining pattern than spirally oriented GFF bands.

Keywords: concrete cylinder, externally, GFF

1. INTRODUCTION

Repair and rehabilitation of deficient structures using externally bonded Fibre Reinforced Polymer (FRP) has become more popular in civil engineering arena due to its excellent characteristics such as high strength to weight ratio and resistance to corrosion. Several experimental investigations (Chaallal et al, 2006; Kumutha et al, 2007; Pessiki et al, 2001; Youssef et al, 2007; Hadi 2006)have been conducted for evaluating the axial strength of columns under axial concentric load. They were focused much on variables such as cross section of columns (Youssef et al, 2007) thickness (Kumutha et al, 2007) and types of FRP reinforcement (Hadi 2006; Youssef et al, 2007). Their results show that the compressive strength of columns could be affected with all those test variables. Moreover, the degree of confinement is also influenced with other parameters such as internal transverse and longitudinal steel reinforcements and grade of concrete. In 2003, Xiao and Wu have used two different grades of concrete and thickness of FRP, but they focused more on the effect of various types of FRP composite jackets: namely, Carbon and E-glass FRP composites. They found that the performance of the confined concrete was dominated by the composite confinement modulus however; the effect of concrete strength is not clearly addressed.

Generally the confinement mechanism of reinforced concrete columns can be increased by adding steel links along the lateral direction. The compression members have been confined with lateral steel ties either in the form of closed steel ties or in the form of spiral steel ties along the circumferential direction. Researchers (Youssef et al, 2007; Kumutha et al, 2007; Hadi, 2006; Youssef et al, 2007) have conducted their investigations using full confinement however the effects of using FRP reinforcement in the form of discrete bands have not been extensively addressed.

This paper presents the effect of discrete GFF bands on high strength and normal strength concrete cylinders under axial concentric load. The effects of (1) spacing of GFF bands, (2) orientation of GFF bands, (3) amount and number of GFF reinforcement, and (4) grade of concrete are addressed. The stress-strain profile of the GFF confined normal and high strength concrete cylinders are addressed.

2. EXPERIMENTAL PROGRAM

2.1 Fabrication and Material Properties

Twelve standard cylinders of dimension 150mm x 300mm were cast using two different grades of concrete: namely, normal (labeled as N) and high (labeled as H) strength concrete. The achieved average characteristic compressive strength of normal and high strength concrete was 35.93MPa and 45.40MPa, respectively. These values were determined by preparing three cubes for both the grades of concrete.

All cylinders were wrapped externally using discrete GFF reinforcements except for control cylinders N1 and H1. A two-part epoxy resin, sikadur®-330 resin/filler components A and B, was used to impregnate the GFF reinforcement. The mix ratio of hardener and resin was 1: 4. The tensile strength, modulus of elasticity, thickness, and elongation at break of GFF bands is 2,300MPa, 76,000MPa, 0.172mm, and 2.8% respectively [Sika manufacturer's manual]. The externally confined GFF cylinders were kept at room temperature for 7 days to ensure that the epoxy is properly cured and non-sticky.

Out of twelve cylinders, two specimens were tested without GFF bands and the rest of ten cylinders were tested with GFF bands. Four different types of test variables were used in this investigation: (1) spacing of GFF bands, (2) orientation of GFF bands, (3) amount and number of GFF reinforcement, and (4) grade of concrete.

2.2 Test Procedure and Installation

The unconfined and GFF-confined concrete cylinders were tested to failure under monotonically increasing concentric axial load. Prior to the application of load, the specimens were mounted inside the compressometer to measure the vertical displacement. Fig. 1 portrays the experimental set-up of test specimen. In order to avoid the load eccentricity and distribute the load uniformly, the surface of the cylinders was properly capped.

Fig. 1: Experimental set-up of test specimen

3. RESULTS AND DISCUSSION

Table 1 shows the summary of experimental results for unconfined and GFF-confined normal and high strength concrete cylinders. From the experimental investigation, it can be seen that, the performance of the GFF-confined columns was varied with respect to the test variables. The achieved degree of confinement was varied between 12% and 25% for GFF-confined normal concrete cylinders and 33% to 47% for GFF-confined high strength concrete cylinders. It was found that increasing the grade of concrete affects the degree of confinement of GFF-strengthened concrete cylinders.

(a)L1 (b)L2 (c)L3

Fig. 2 Failure patterns of columns (a) splitting with crushing of concrete (b) debonding of GFF (c) compression failure at unwrapped portions

(a)H2 (b)H5

Fig. 3 Failure patterns of columns (a) debonding of GFF (b) compression failure at unwrapped portion

Table 1 External reinforcement details

Specimen	W_f (mm)	Amount of GFF (mm^2)	Spacing (mm)	No. of plies	Orientation	Axial stress (MPa)	Enhance-ment (%)	Axial strain (mm/mm)	Modes of Failure
N1	-	-	-	-	-	30.61	-	0.0044	Spalling and Splitting
N2	60	176, 000	35	1	± 45º	34.07	11.29	0.0060	Debonding of GFF bands
N3	60	94, 200	35	1	0º	38.25	24.94	0.0088	Compression in uncovered concrete bands
N4	60	152, 000	75	2	0º	36.36	18.43	0.0078	
N5	60	76, 000	75	1	0º	36.05	17.78	0.0074	
N6	60	141, 300	Full	1	0º	35.21	15.01	0.0081	No failure
H1	-	-	-	-	-	37.17	-	0.0045	Compression failure
H2	60	88, 000	35	1	+45º	49.42	32.92	0.0057	Debonding of GFF bands
H3	60	94, 200	35	1	0º	52.18	40.35	0.0057	Compression in uncovered concrete bands
H4	60	152, 000	75	2	0º	52.12	40.18	0.0078	
H5	60	76, 000	75	1	0º	52.12	40.18	0.0071	
H6	60	141, 300	Full	1	0º	53.09	42.79	0.0069	No failure

Fig. 2 and 3 show the failure patterns of the tested unconfined and GFF confined cylinders in series-N and H. The unconfined specimen N1 failed in conjunction with splitting and spalling of concrete, whereas in series-H, the unconfined specimen H1 was controlled by compression failure. For partially confined normal strength concrete cylinders with different spacing and thickness of discrete GFF bands (i.e. N3, N4, and N5), the failure was associated with compression in unwrapped segment of the cylinder. Similar failure trend was also observed in partially GFF confined high strength concrete cylinders (i.e. H3, H4, and H5). However, in case of spirally confined normal and high strength cylinders (i.e. $+45^0$ and $\pm 45^0$), debonding of GFF bands was observed from the bottom of the GFF confined cylinders. It confirms that the orientation, thickness, and spacing of GFF bands could affect the failure pattern of GFF-confined normal and high strength concrete cylinders. No failure was observed in the fully confined GFF normal and high strength concrete cylinders.

3.1 Effect of Orientation of GFF bands

In order to evaluate the effectiveness of orientation of GFF bands, the cylinders confined with horizontal (i.e. 0º) and spiral (i.e. 45º) GFF bands were compared. The application of horizontally oriented GFF bands on high strength concrete cylinder H3 (i.e. 0^0) attained a maximum confinement of 6% greater over the specimen H2 wrapped at 45^0 orientation. For specimen N2 with GFF bands oriented at $\pm 45^0$, the amount of GFF reinforcement used was 1.9 times greater than the specimen N3 wrapped at 0^0 orientation, however the degree of confinement in specimen N2 was 12% less than N3. This result shows that the effect of spirally confined GFF-cylinders was not significant even the amount of GFF reinforcement used in spirally confined GFF cylinders is greater than horizontally wrapped GFF cylinders. It was found that the horizontal orientation is the most appropriate confining pattern for the GFF confined cylinders under compression.

3.2 Effect of Spacing and Thickness of GFF Bands

Two different spacing's of GFF bands of $0.58W_f$ (W_f - width of GFF bands) and $0.8W_f$ were used. The GFF band for specimens N3 & H3 and N5 & H5 were spaced at $0.58W_f$ and $0.8W_f$, respectively. The measured compressive strength of specimen N3 was 6% greater than N5 as the decrease in spacing of GFF bands strips. In case of high strength concrete cylinders (H3 and H5), the effect on spacing of GFF bands was very minimal. It can be concluded from the experimental results, the confinement of concrete cylinders using discrete GFF bands could be significantly decreased when the spacing of GFF bands is greater less than $0.58w_f$.

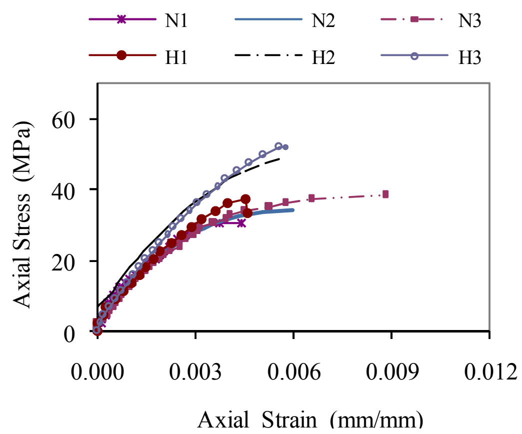
The amount of GFF reinforcement used for specimens N4 and H4 was twice that of specimens N5 and H5, respectively. For specimens wrapped at a spacing of $0.8W_f$ bands, the obtained result shows that the effect of increasing the thickness of GFF bands (i.e. from one to two GFF bands) does not show any difference in compressive strength of GFF-confined normal and high strength concrete cylinders. It is noted that the degree of confinement decreases even with more number of GFF plies due to the increased spacing of GFF bands. Therefore, it is very essential to control the spacing of GFF reinforcement when the GFF reinforcement is applied in the form of discrete bands/strips.

3.3 Effect of Wrapping Layout

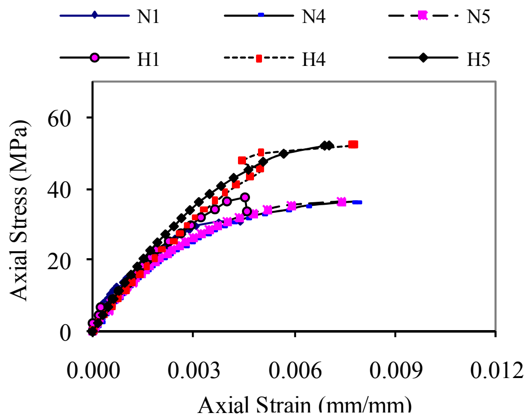
This investigation used two different types of wrapping layouts; namely full wrapping and discrete GFF bands. Values of fully GFF confined normal strength concrete cylinder N6 was approximately 9% less than partially confined cylinder using GFF bands. However, in case of high strength concrete cylinders, no significant gain in strength was observed in fully confined cylinders. It is evident that the application of discrete GFF bands could provide better results same as full confinement but it has some limitations such as width and spacing of GFF of bands.

3.4 Stress-Strain Profile

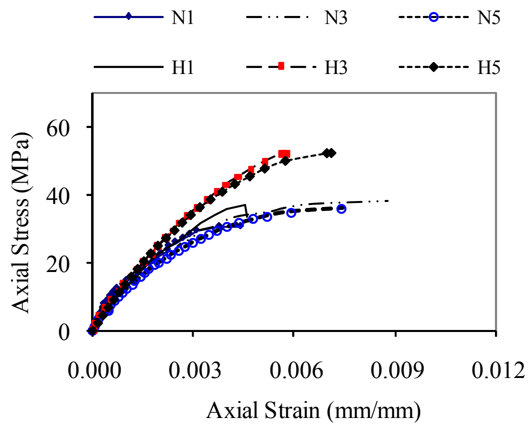
Fig. 4(a)-(d) portray the axial stress-strain profile of the unconfined and GFF confined normal and high strength cylinders with different test variables. These curves have two distinct slopes; the early stage of the curve was linear prior to the failure of concrete and second part was non-linear zone where the externally applied GFF reinforcement bands become more active. The stress-strain behaviour of the GFF confined normal and high strength concrete cylinders was almost similar to that of unconfined concrete cylinders prior to the failure. As the concrete core expands in the GFF confined cylinders, the internal pressure excretes in the circumferential direction which initiates the GFF bands to build lateral confining pressure by resisting the compressive force. Thus, the lateral confinement pressure in the GFF confined concrete cylinders was not only enhanced the compressive strength but also improved the ductility.



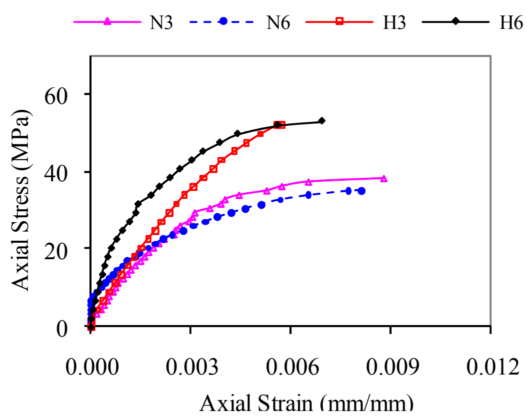
(a)



(b)



(c)



(d)

Fig. 4 Axial stress-strain profile for unconfined and confined normal high strength concrete cylinders with different test variables (a) orientation of GFF bands (b) Spacing of GFF bands (c) Number of GFF bands and (d) Wrapping layout

Table 1 shows the axial strain value at peak load for unconfined and GFF confined normal and high strength concrete cylinders. The observed axial peak strain in unconfined normal strength concrete cylinder N1 was similar to the unconfined high strength concrete cylinder H1, whereas the ultimate compressive strength was not the same. It can be seen that the GFF confined normal strength concrete cylinders attained more ductility over the GFF confined high strength concrete cylinders. The strain values of the GFF confined high strength concrete cylinders were relatively less when compared to the GFF confined normal strength concrete cylinders. From Fig. 4 it can be seen that the stiffness of the GFF confined high strength concrete cylinders was higher than GFF confined normal concrete cylinders. Results confirm that the grade of concrete could affect the performance of GFF confined concrete cylinders with respect to their test variables.

4. CONCLUSIONS

This investigation was conducted to study the effects of GFF bands on normal and high strength concrete cylinders under concentric load. Following conclusions can be drawn from this investigation:

- Better enhancement was achieved in GFF confined high strength concrete cylinders than the GFF confined normal strength concrete cylinders. The application of GFF bands was not only enhanced the strength of the GFF confined concrete cylinders but also improved the ductility of the GFF confined concrete cylinders over their control cylinders. It is also noteworthy to highlight that the ductile behaviour of GFF confined high strength concrete cylinders was relatively less than normal strength concrete.

- It was suggested that the confinement of concrete cylinders using discrete GFF bands could be significantly decreased when the spacing of GFF bands is greater less than $0.58w_f$.
- Results confirm that the application of horizontally oriented GFF bands is the most effective confining pattern than spirally oriented GFF bands.
- It is evident that the application of discrete GFF bands could provide better results same as full confinement but it has some limitations such as width and spacing of GFF of bands.

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