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The Influence of Steel Fiber on the Stress-Strain Behavior of Confined Concrete

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Abstract: This paper presents the result of an experimental study of confined concrete to evaluate the stress-strain behavior of fiber-reinforced concrete, which includes strength and ductility. The effectiveness of steel fibers in influencing the stress-strain behavior was also evaluated by creating a conventional concrete as a control specimen. The experimental results showed that there was a decrease in the value of the increased strength of confined concrete (f'_{cc}/f'_{co}) when the compressive strength of the concrete increased. Reducing the spaces of lateral reinforcement spaces will also increase the strength and ductility of confined concrete. The comparison of experimental results with various confinement models shows that there are substantial differences in the peak stress and the descending behavior of confined fiber concrete.

Keywords: *steel fiber; confinement; lateral reinforcement; stress-strain*

1. Introduction

Compared to conventional concrete, laterally reinforced concrete has potential upsides in strength and ductility, specifically for column application. Lateral reinforcements have various functions: they are instrumental in curbing lateral swelling that occurs due to axial compressive loads, prevents buckling in the longitudinal reinforcement, and prevents shear failure in the column. The higher the axial loads on the column, the more lateral reinforcement is needed for to maintain a strong and ductile structure [Sharma et al. 2007, Antonius & Imran 2012, Antonius, 2014]. Lateral reinforcement also increases residual strength. Based on the recently conducted research on high quality concrete with 60-120 MPa compressive strength, Mansur et al. (1997) found that while the quality of all steel fiber specimens was similar, the addition of confinement in one of the specimens actually increased the residual strength that was previously 20 MPa to 40-50 MPa. This development proves that residual strength depends on the lateral stress in confinement, not on the quality of the concrete.

In this research, the high-quality confined concrete shows a different behavior compared to the confined normal quality concrete. If the lateral, longitudinal and cross-section dimension ratio of the reinforcement is similar, the confinement will be more effective in normal confined concrete, which means that confinements provide greater strength and ductility in normal-quality concrete compared to high-quality concrete. The brittle nature of the concrete can be overcome by installing fiber [Cement & Concrete Institute 2010], this measure is also considered effective to increase strength and reduce deflection [Mansur et al., 1997]. On the other hand, Hadi (2009) and Khalil et al. (2012) explain that increasing the compressive strength of fiber-reinforced concrete will result in a more brittle failure mode. Installing fibers in a certain volume is also known to increase strength and ductility.

This paper discusses the experiment results of laterally-confined concrete by meticulously reviewing the design parameters of compressive strength, the spacing of lateral confinement, and the addition of steel fibers. The results were also compared with the developed confinement models to determine the accuracy of the models in predicting the stress-strain behavior of confined fiber-reinforced concrete.

2. The developed confinement model

The confinement model is needed to predict the failure of column or wall, particularly against seismic loads. Although this practice has yet to be generally recognized, several confinement models have been utilized as the basis for design planning. The following sections will examine two confinement models and their constituents.

2.1. Mander et al. Model (1988)

Mander et al. propose a confinement model based on the results of full-scale columns experiments using normal quality concrete. The column specimens are comprised of normal/non-fiber concrete. However, it has been established that Mander's model is more ductile compared to other confinement models. The following equation is the component of stress-strain curve:

$$f_c = \frac{f'_{cc}\,xr}{r-1+x^r} \quad (1)$$

where:

$$x = \frac{\pounds_c}{\pounds_{cc}} \quad (2)$$

$$r = \frac{E_c}{E_c - E_{\sec}} \quad (3)$$

$$E_c = 5000\sqrt{f'_{co}} \quad \text{MPa} \quad (4)$$

and

$$E_{\sec} = \frac{f'_{cc}}{\pounds_{cc}} \quad (5)$$

The increased strength of confined concrete was referenced based on Willam-Warnke's melting criteria as follows:

$$\frac{f'_{cc}}{f'_{co}} = -1.254 + 2.254\sqrt{1+\frac{7.94 f_l}{f'_{co}}} - 2\frac{f_l}{f'_{co}} \quad (6)$$

and the peak stress of confined concrete equation is:

$$\pounds_{cc} = \pounds_{co}\left[1 + 5\left(\frac{f'_{cc}}{f'_{co}} - 1\right)\right] \quad (7)$$

2.2. Campione Model (2002)

Based on numerous experiments, Campione (2002) proposed a confinement model of fiber-reinforced concrete where the stress-strain curve is divided into two branches. The first one is the ascending branch:

$$\frac{\pm}{f'_c} = \frac{(£/£_0)}{-1+(£/£_0)} \tag{8}$$

the second one is the descending branch:

$$\frac{\pm}{f'_c} = ¦_d \exp\left[-k_d\left(\frac{£}{£_o} - x_d\right)^{a}\right] \tag{9}$$

Furthermore, the parameter values of the previous equation are:

$$= A + B(RI)^c \tag{10}$$

where
A = 0.5811;
B = 1.93
C = -0.740

Hence,

$$= \frac{E_c}{E_c - (f'_c/£_0)} \tag{11}$$

The equations to calculate the increased strength and strain of confined concrete are:

$$\frac{f'_{cc}}{f'_c} = 1 + 2.1\left(k_e \frac{f_l}{f'_c}\right)^{0.7} \tag{12}$$

$$\frac{£_{cc}}{£_o} = 1 + 5k_1\left(k_e \frac{f_l}{f'_c}\right)^{0.7} \tag{13}$$

3. Experimental program

This research was conducted using an experimental method by testing both the normal and fiber-reinforced specimens with the dimension of 125x125x310 mm. Figure 1 shows the cross-section of the column, while Table 1 shows the compositions of the specimens. The mix design process in this research conforms to the ACI Committee 544 guideline,

Table 1. Composition of concrete mixture of test specimens

Materials	Target f’c=30 MPa	Target f’c=50 MPa	Target f’c=70 MPa
Cement (Kg/m3)	350	419.98	485
Fly Ash (Kg/m3)	-	74.11	82.83
Water (Lt/m3)	200	160	140
Viscocrete 0,5% (lt/m3)	-	6.228	9.28
Fine Aggregate (Kg/m3)	722.9	696.62	662.07
Coarse Aggregate (Kg/m3)	886.8	1044.93	1080.22

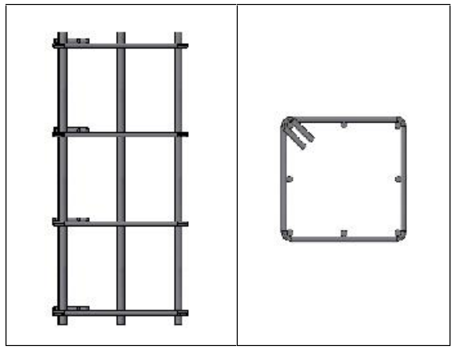
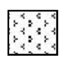
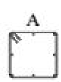


Fig. 1. Lateral reinforcement configuration of the specimens

4. Results and discussion

Table 2 presents several data of the test results: the compressive strength of the 150/300 cylinder at 28th day (f'_c), the peak stress of unconfined concrete (f'_{co}), the peak stress of confined concrete (f'_{cc}), the increased strength of confined concrete (K = f'_{cc}/f'_{co}), the peak strain of unconfined concrete (ε_{co}'), and the peak strain of confined concrete peak (ε_{cc}').

Table 2. Experimental Results

Specimen	f'_c (MPa)	Configuration	Lateral Reinforcement			f_{cc}' (MPa)	ε_{co}'	ε_{cc}'	K
			Ø-s (mm)	f_y (MPa)	ρ_h (%)				
UFS 30	29.50		-	-	-	26.33	0.0037	0.0056	1.05
UFS 55	51.00		-	-	-	44.75	0.0035	0.0069	1.035
UFS 80	71.20		-	-	-	61.72	0.0032	0.0079	1.02
NSA 30	29.50		6 - 60	415	1.58	28.81	0.0037	0.0085	1.15
NSA 55	51.00		6 - 60	415	1.58	48.91	0.0035	0.0087	1.13
NSA 80	71.20		6 - 60	415	1.58	65.66	0.0032	0.0102	1.08
FSA 1	29.50		6 - 60	415	1.58	46.44	0.0037	0.0098	1.85
FSA 2	29.50		6 - 100	415	0.95	27.44	0.0037	0.0120	1.06
FSA 3	51.00		6 - 60	415	1.58	53.26	0.0035	0.0182	1.23

The test shows that a higher compressive strength of the concrete will result in higher peak stress and strain on the normal concrete without lateral reinforcement (UFS), the laterally-reinforced normal concrete (NSA), and the laterally-reinforced fibrous concrete (FSA and FSB). The test also indicates that the concrete is in the process of collapsing after exceeding the steep peak stress. It turns out that higher quality concrete has more brittle characteristics.

4.1. Effect of concrete strength

In general, increasing the compressive strength of concrete tend to reduce compressive stress and ductility of concrete. This applies on normal concrete and fiber-reinforced concrete, for both unconfined and confined. Table 2, Figures 2, 3 and 4 describe this behavior. Figure 2 shows the stress-strain behavior of unconfined fiber-reinforced concrete, Figure 3 shows the stress-strain behavior of confined normal concrete, and Figure 4 shows the stress-strain behavior of confined fiber-reinforced concrete.

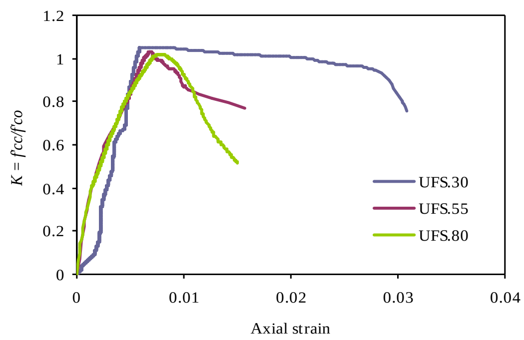


Fig. 2. Stress-strain curve of unconfined fiber-reinforced concrete

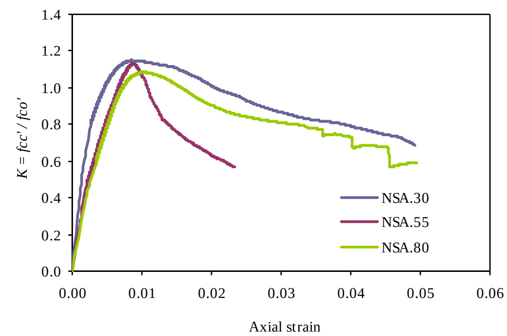


Fig. 3. Stress-strain curves of confined normal concrete with various f'_c

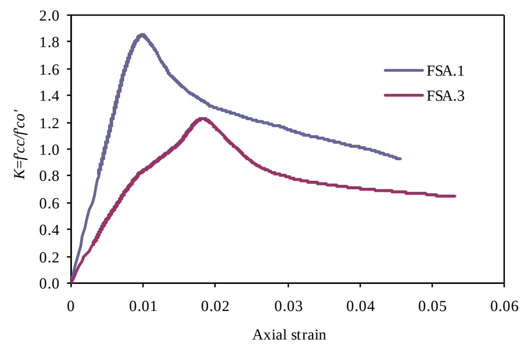


Fig. 4. Stress-strain behavior of confined fiber-reinforced concrete with various f'_c

4.2. Effect of steel fiber

Steel fibers have significant contribution in increasing the strength of confined concrete (K) and ductility. This applies to specimens which have the compressive strength of 29.5 MPa and 51 MPa (Figures 5 and 6). This behavior indicates that the matrix bond in fiber-reinforced concrete is more compact, which means fiber-reinforced concrete has a bigger capacity than normal concrete.

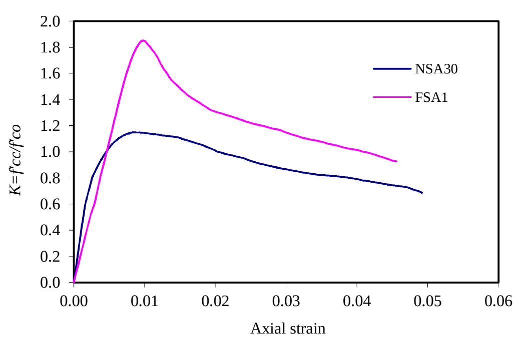


Fig. 5. Effect of steel fiber on the stress-strain behavior of confined concrete; $f'_c = 29.5$ MPa

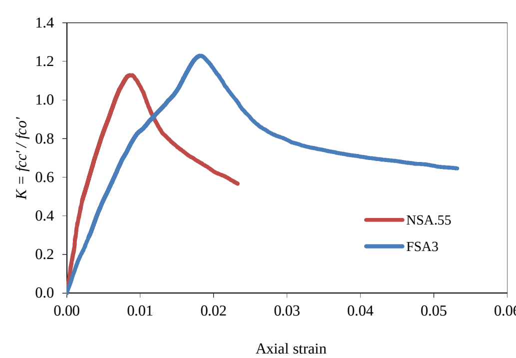


Fig. 6. Effect of steel fiber on the stress-strain behavior of confined concrete; $f'_c = 51$ MPa

4.3. Effect of tie/lateral confinement spacing

Similar to the behavior that typically occurs in confined normal concrete, the reduction of lateral reinforcement spacing in fiber-reinforced concrete also increase the strength and ductility of fiber-reinforced confined concrete (Figure 7).

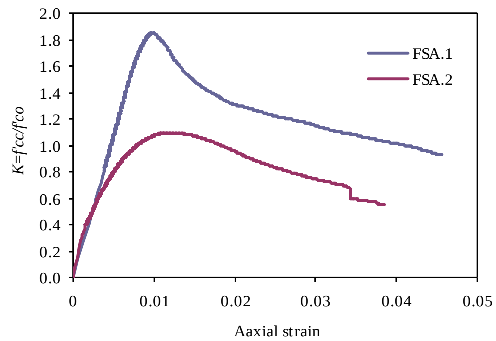


Fig. 7. Stress-strain curve of fiber-reinforced concrete with various spacing

5. Confinement models experimental comparison

The experimental results of the stress-strain behavior of confined fiber-reinforced concrete are will later be predicted using Mander and Campione models. Figures 8, 9 and 10 show the comparison curve. The results of the comparison show that there are significant characteristic differences, particularly in the peak stress of confined concrete (f'_{cc}) and the post-peak curve of confined concrete. This means that developing a new model that suits the design parameters in accordance experiment is necessary.

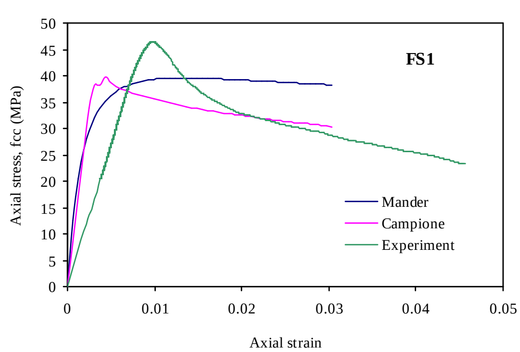


Fig. 8. Confinement models vs experiment; FS1

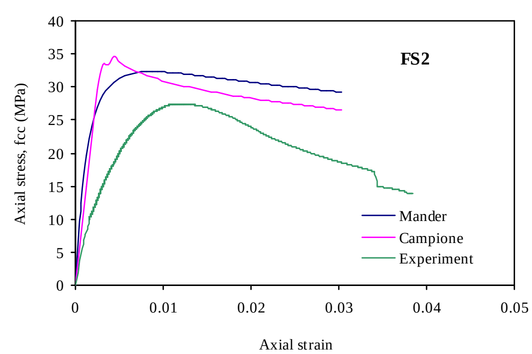


Fig. 9. Confinement models vs experiment; FS2

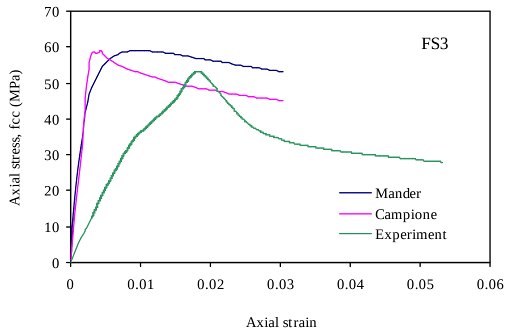


Fig. 10. Confinement models vs experiment; FS3

6. Conclusion

Normal and fiber-reinforced concrete, both confined and unconfined, have similar properties in each comparison, which are the increased strength of confined concrete (*K*) and ductility. The value of K and ductility tend to decrease, if the compressive strength is increased and the spacing of lateral reinforcement is wider. Steel fibers have significant contribution in increasing the value of K and ductility of confined concrete. The reviewed confinement models in this paper have substantial differences in stress-strain behavior, which means a new confinement model needs to be developed in accordance with the parameters in this paper.

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