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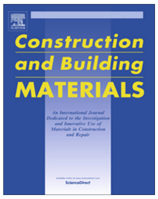

# Fiber-reinforced concrete containing ultra high-strength micro steel fibers under active confinement

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## HIGHLIGHTS

- Effects of confining pressure and steel fiber volume fraction on compressive behavior of SFRCs are studied.
- Four SFRCs containing ultra high-strength micro steel fibers at two volume fractions of 1% and 2% are prepared.
- Compressive strength and peak axial strain of SFRCs increase with an increase in the fiber volume fraction.
- Axial strain of SFRC at a given lateral strain increases with an increase in the fiber volume fraction.
- Increasing fiber volume fraction leads to axial stress-strain curves with more shallow post-peak branches.

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## ABSTRACT

This paper presents an experimental study on the compressive behavior of steel fiber-reinforced concrete (SFRC) under active confining pressure. Four different SFRC mixes containing ultra high-strength micro steel fibers at two volume fractions of 1% and 2% were prepared to produce concretes with two different target compressive strengths of 50 and 100 MPa. The active confining pressure was applied on SFRC using a Hoek cell at different confinement levels of 5, 10, 15, and 25 MPa. The effects of confining pressure and steel fiber volume fraction on the compressive behavior of concrete were examined through the axial compression tests on unconfined and actively confined SFRCs. The results show that the axial strength and peak axial strain of SFRCs increase with an increase in the fiber volume fraction. The fiber volume fraction also affects the post-peak branch trend of the axial stress-strain relationships of SFRCs under a given confinement level. SFRCs with a higher volume fraction exhibit more shallow post-peak branches than those of SFRCs with a lower volume fraction. The results also show that the axial strain of SFRC at a given lateral strain increases with an increase in the volume fraction, indicating a reduced rate of dilation of SFRCs at a higher volume fraction. These promising findings point to the great potential of the use of ultra high-strength micro steel fibers in the development of high performance composite structural members in applications where the concrete will be subjected to lateral confinement.

## 1. Introduction

In recent years, high-strength concrete (HSC) has become a promising alternative in the construction of new high performance columns owing to its superior structural properties over normal-strength concrete (NSC) [1,2]. However, because of the inherent brittleness of conventional HSC, its application has been somewhat limited especially in constructions undertaken in seismically active zones [3]. On the other hand, studies have shown that the use of steel fibers can improve the brittle behavior of conventional concrete [4–10]. The distribution of internal steel fibers in the concrete decreases isolated major crack formations by reinforcing the bridge of microcracks, which leads to a more even and controlled crack propagation [7]. This thereby results in improvements in the ductility and strength of concrete.

A large number of experimental investigations have been conducted to understand the mechanical behavior of steel fiber-reinforced concrete (SFRC) columns (e.g. [3,11–22]). Existing

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studies have shown that the steel fiber parameters, the volume fraction ($V_f$) and aspect ratio ($A_R$), influence the stress-strain relationship of SFRC. It was shown that, at a given $V_f$, the compressive strength ($f'_{co}$) and corresponding axial strain ($\varepsilon_{co}$) of concrete decrease with an increase in $A_R$. On the other hand, it was shown that an increase in $V_f$ at a given $A_R$ leads to an increase in $f'_{co}$ and $\varepsilon_{co}$. It was also shown that when steel fibers are uniformly dispersed in the concrete, significant improvements can be obtained in the mechanical properties of concrete [18,21]. Therefore, due to its superior performance compared to that of conventional concrete, SFRC has a great potential to serve as a high performance concrete in structural applications.

It is now well known that significant improvements in the ductility and compressive strength of concrete can be achieved by its lateral confinement [23,34]. Active confinement is a confinement method in which a constant lateral confining pressure is applied to concrete [35]. In order to understand the mechanical behavior of SFRCs under lateral confinement, the study of the actively confined concrete is of vital importance to simulate the behavior of concrete under constant confining pressure (e.g. steel-confined concrete) and varying confining pressure (e.g. fiber-reinforced polymer (FRP)-confined concrete). Although a number of experimental studies have been performed to date to understand the mechanical behavior of confined SFRCs under axial compression (e.g. [5,7,30,36,37]), only two of these studies have dealt with the

**Table 1**
Chemical composition and physical properties of cementitious materials.

| Item | Cementitious materials (%) | |
|---|---|---|
| | Ordinary Portland cement | Silica fume |
| $SiO_2$ | 21.4 | 92.5 |
| $ZrO_2 + HfO_2$ | – | 5.50 |
| $Al_2O_3$ | 5.55 | 0.35 |
| $Fe_2O_3$ | 3.46 | 0.40 |
| $P_2O_5$ | – | 0.30 |
| CaO | 64.0 | 0.03 |
| MgO | 1.86 | – |
| $SO_3$ | 1.42 | 0.90 |
| $K_2O$ | 0.54 | 0.02 |
| $Na_2O$ | 0.26 | 0.02 |
| | *Compounds* | |
| $C_3S$ | 51.0 | – |
| $C_2S$ | 23.1 | – |
| $C_3A$ | 8.85 | – |
| $C_4AF$ | 10.5 | – |
| | *Fineness* | |
| Surface area ($m^2$/kg) | 330 | 18,000 |

**Table 2**
Material properties of ultra high-strength micro steel fibers.

| Length (mm) | Diameter (mm) | Aspect ratio | Tensile strength (MPa) |
|---|---|---|---|
| 13 | 0.18 | 73 | 2850 |

**Table 3**
Mix proportions of the concrete.

| Concrete mix | C50-1 | C50-2 | C100-1 | C100-2 |
|---|---|---|---|---|
| Cement (kg/$m^3$) | 375 | 375 | 506 | 506 |
| Silica Fume (kg/$m^3$) | – | – | 44 | 44 |
| Sand (kg/$m^3$) | 720 | 720 | 700 | 700 |
| Coarse Aggregate (kg/$m^3$) | 1053 | 1026 | 1023 | 996 |
| Water (kg/$m^3$) | 176 | 176 | 145 | 145 |
| Superplasticizer (kg/$m^3$) | 5 | 5 | 25 | 25 |
| w/b* | 0.479 | 0.479 | 0.295 | 0.295 |
| Volume Fraction ($V_f$) (%) | 1 | 2 | 1 | 2 |
| Fiber (kg/$m^3$) | 78 | 156 | 78 | 156 |
| Slump (mm) | 140 | 125 | 175 | 130 |
| Hardened Density (kg/$m^3$) | 2449 | 2526 | 2476 | 2555 |

* Including the water coming from the superplasticizer (i.e. 70% water by weight).

**Fig. 1.** SFRC specimens.

**Fig. 2.** Universal testing machine.

**Table 4**
Compression test results of unconfined specimens.

| Mix | $f'_{co}$ (MPa) | | | $\varepsilon_{co}$ (%) |
|---|---|---|---|---|
| | 7-day | 14-day | 28-day | 28-day |
| C50-1 | 32.1 | 43.5 | 51.7 | 0.30 |
| C50-2 | 47.7 | 58.3 | 64.1 | 0.32 |
| C100-1 | 74.7 | 90.1 | 103.2 | 0.35 |
| C100-2 | 79.7 | 96.6 | 113.5 | 0.37 |