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# Experimental investigation on high strength concrete columns reinforced with B500

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**Abstract** Concrete is a common material in construction, but it is weak in tension, often destroyed with cracks due to plastic and drying shrinkage. It was possible to use the introduction of separate short fibers into concrete to counter and prevent the spread of cracks. High strength concrete (HSC) considered as an improved material which is used for bridges, offshore structures and high rise building. The addition of fiber to HSC enhances durability, reduces shrinkage, and decreases chemical attack deterioration. This research presents an experimental program to clear the effect of steel fiber content, stirrups ratio, longitudinal steel ratio and grade on behavior of high-strength fiber reinforced concrete (HSFRC) columns subjected to axial load. Six columns have been cast and tested with compressive strength of 1000kg/cm$^2$ and steel fiber content of 0, 20, 40kg/m$^3$. This paper highlights the results to investigate variables on the gain of strength, cracking load, ultimate load, failure mode and ductility. The experimental investigation provided that increasing amount of longitudinal reinforcement tends to increasing in ultimate load by 5%, increasing in strain at yield load in steel with 23%, while in concrete the strain was decreased by 36%. The load capacity was higher when the steel type was changed from B500DWR to B500CWR.

**Keywords:** High-Strength Concrete; Steel Fiber; Column; Ductility; Axial load, B500 Steel

## 1 Introduction

By using high strength concrete, columns can be made smaller and, as a result, the dead load on the foundation system can be decreased. Moreover, reducing the column size can increase the available floor space for a building. With greater elastic modulus, using high strength concrete can increase the rigidity of the structural component, which lowers deformation under the same load. Because the micro structure is denser, high-strength concrete is more resistant to rust and low temperatures. Ultra high strength concrete (UHSC's) high mechanical properties and durability make it an obvious choice for both technical and financial reasons [1, 2, 3]. According to the findings of Demer and Neale [4] HSC is noticeably more brittle than standard strength concrete. This may cause sudden failure than conventional strength concrete under high loads. The challenge in using HSC is to address the problem of the brittleness in this material [5].
Foster developed a model to calculate the fiber content required for ductility in both conventional and HSC columns. He came to the conclusion that the ductility and strength of concrete are negatively related. Because of this, HSC columns are fragile, fracture easily, and burst under concentric compression. As a result, designing high-strength concrete columns becomes difficult, particularly in seismically active areas. Column ductility can be increased through confinement or adding steel fibers in the concrete mixture [6].
The structural performance of steel fiber reinforced concrete columns is reviewed in a paper by Al-Qabbani et al. Columns subjected to various loading scenarios, such as coupled cyclic loads and compression lateral loads, as well as eccentric or concentric compression loads were tested. Two categories will be covered in this search: High strength concrete reinforced with steel fiber and HSC columns devoid of fiber. Concrete strength, transverse reinforcing characteristics, and axial load ratio were among the criteria in addition to the principal operator (steel fiber content). The findings show that the addition of steel fiber improves flexural strength, fatigue life, and resistance while postponing the outside concrete layer's spalling failure and the longitudinal steel reinforcing bars' outward buckling. The ideal range for steel fiber volume fraction is 0.5% to 2% (by weight), and the cover of the

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columns did not spall away when 2% of steel fibers were added to the concrete mixture [7].

Hassan, looked at the mechanical characteristics of fiber high-strength concrete (HSC) specimens as well as how these specimens behaved under concentric stresses. Under axial loads, sixteen square columns were tested. He came to the conclusion that there was a 9.75% gain in compressive strength with the higher fiber content [8].

A minimum transversal reinforcement ratio is included in the design regulations to ensure the columns' ductile behavior and, consequently, their safety. This ratio typically relates to the degree of axial load and the strength of the concrete, among other factors [9-11].

Using steel fibers in conjunction with transverse reinforcement can lower the transverse reinforcement ratio needed by codes in the event of seismic design [11-13]. Code recommendations, however, disregard the benefits of steel fibers [14].

The use of short discrete fibers in the concrete mix has been discovered to boost the compressive strength and ductility of HSC [15-17]. Additionally, they demonstrated how the relatively large amount of confinement reinforcement needed by design standards ACI 318, [18] and Canadian Standard Association [19] for HSC columns may actually be reduced by combining discrete fibers with transverse steel reinforcement. Preventing the early separation of the concrete cover is another benefit of including discrete fibers into HSC mixes in reinforced concrete columns. The last several decades have seen a rise in interest in the use of fiber-reinforced concrete (FRC) for structural elements [20, 21].

Recent research discovered that the use of steel fiber improves the deformation capacity of concrete columns subjected to axial load and continuous eccentricity and delays the spalling of concrete [22-25].

Presence of steel fibers control the cracks not prevent it. They are used to improve post-cracking tensile response [26, 27].

Vougiouka, and Papadatou discovered that steel fibers are discontinuous and are dispersed randomly in the concrete matrix exactly like other fibers [28, 29, 30]. According to Paultre et al. [31], these properties enable the fibers to bridge fractures in any direction and to transmit stress more effectively across all cracks, enhancing post-cracking shear and flexural resistance.

The primary benefits of steel fiber integration in compression, akin to the tensile response, are increased toughness and post-peak ductility [27]. The best alignment for the fibers would be in the direction of the greatest tensile stress. When significant stresses occur in the cement matrix, fibers are particularly helpful [32-34]. According to testing, adding more fiber would improve toughness, ductility, and strength [35, 36]. An increase in fiber content increases the likelihood that more fibers will cross a fracture, improving the behavior of the concrete matrix after a crack [36].

The effect of additional steel fiber on the stress-strain relationship and axial compression performance of restricted high-strength recycled aggregate concrete (HSRAC) columns was examined by Xiao Liu et al. They discovered that the inclusion of steel fiber with a volume composition of 1% increased the conclusive strain of hoop-confined HSRAC by 55.45% and that steel fibers could fulfill the impairment of the low deformation ability of HSRAC [37].

Atea investigates the joint effect of ties and fibers on the behavior of reinforced columns in order to increase their ductility. He gives an expressive estimate of the ductility and strength of short concrete columns with normal and high presentation, restricted by tie both with and without fibers made of polypropylene and steel. Five concrete columns measuring 10 by 10 by 100 centimeters were cast. Concrete strength, the volume percentage of longitudinal reinforcement (4.52%), the volumetric ratio of lateral reinforcement (the space between ties) (5.58%), the type of fibers (hooked steel fiber and polypropylene), and the phase ratio of steel fibers (100 and 60) were the factors that were tested. Axial load testing was conducted on the square column. The findings showed that adding steel fibers to high presentation concrete increased its compressive strength, splitting tensile strength, flexural strength, and static modulus of elasticity. The steel fibers had a volume friction of 0.75% and an aspect ratio of 100% [38].

The response of traditional reinforced concrete columns placed under axial load and a study was conducted on lateral reversal cyclic loading numerically by Rafaa and Akram using the finite element program ABAQUS. The Study examined the impact of concrete compressive strength, column aspect ratio, and longitudinal and transverse reinforcement ratios. They use 8Ø14, 8Ø20, and 8Ø25 mm rebars, respectively, to analyze column specimens with three distinct (ρ) values: 1%, 2.05%, and 3.2%. They discovered that the longitudinal reinforcement ratio and the axial load index had the most effects on the behavior of the columns according to numerical case studies. Additionally, lowering the aspect ratio of columns and raising the concrete's compressive strength increased the column's strength capacity [39].

## 2 Research Significance

The demand for high strength concrete and its usefulness in lowering column size were the main topics of this study. Presenting the findings of an experimental program that looked into the many factors influencing the performance of reinforced high strength columns under axial stress was the goal of this study. Six HSC columns are present in the experimental program.

## 3 Experimental Program

### 3.1 Materials characteristics

Materials that could be found locally were used to cast all test columns. Pure dolomite that had been crushed to a maximum size of 19 mm and a specific gravity of 2.66 was utilized as the coarse aggregate. For fine aggregate, organic clean sand with a specific gravity of 2.5 and a fineness modulus of 2.25, and a particle size of less than 5 mm, was utilized. The aggregates utilized are displayed in Figure 1. Ordinary Portland Cement (CEM I 52.5N), which has a specific gravity of 3.15 based on ASTM C150 [40]. Cement was partially replaced with silica fume, an extremely fine pozzolanic substance with a specific gravity of 2.35. Table 1 indicated the specification of used silica fume. The used superplasticizer, Optima EG 295 HP was added, the properties was appeared in table 2 that met the ASTM C494 types F standards [41]. Steel fiber used in this research is produced by cutting cold drawn high tensile deformed steel wire. The wire is of 55 mm length with wavy shape to have more contact surface (average wave depth 0.65 mm) and circular cross section (1.0 mm diameter). It is suitable for concrete composite because of its higher strength characteristics, also it complies with

ASTM A820 [42]. Figure 2 shows the used steel fiber and table 3 illustrated the specification of the used steel fiber

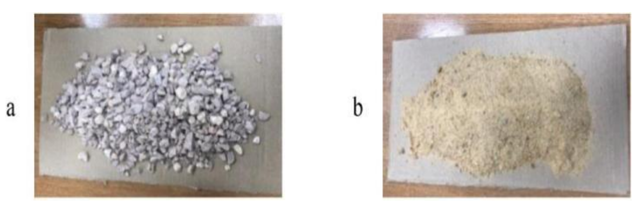


**Fig.1**:The used coarse aggregate and fine aggregate

**Fig.2:**The used steel fiber

#### 3.1.1 The used steel

Two types of steel were used B500DWR ϕ 10 mild steel and B500CWR with two diameters (10 and 12 mm) in the main longitudinal reinforcement. Type B240D-Pof 8 mm diameter was used as stirrups. Table 4 describes the used steel.

**Table 1** Characteristics of the Employed Silica Fume

| Component | Percentage % |
|---|---|
| SiO2 | 89.25 |
| Moisture | 0.2 |
| Free CaO | 0.14 |
| L.O.I | 2.61 |
| Cl- | 0.036 |

**Table 2** Performance Test Data of Optima EG 295 HP

| | |
|---|---|
| Aspect | light brown, freely flowing liquid |
| Relative Density | 1.055± 0.02 at 25℃ |
| PH | ≥ 6 |
| Chloride Ion content | < 0.2% |

**Table 3** Characteristics of the steel fiber utilized

| | |
|---|---|
| Density | 7.870 kg/m³ |
| Melting point | 1480 Celsius |
| Tensile strength | 2400 N/mm² |

### 3.2 Mixtures proportions

In the laboratory, three different mixtures were produced. The control mixture M1 used to cast the reference column CHR was made up of cement, water, natural aggregate, silica fume and super plasticizers. However, the control mixture (M2) used to cast three columnsCH1,CH3 and CH4 included cement, silica fume, water, natural aggregate, 20 kg/m3 (0.25%) steel fiber and super plasticizers.

The third concrete mix M3 was used to cast CH2 consists of same ingredients of Mix2 but the steel fiber content was 40 kg/m$^3$ (nearly 0.5%). Each mix's proportions are displayed in Table 5.

### 3.3. Mixing procedure and curing

The coarse and fine aggregates were mixed for one minute in a dry atmosphere, followed by the addition of cement and silica fume, and another minute of mixing. Following a minute of mixing, half of the mixing water was put to the mixer. After adding the superplasticizer and the leftover water to the mixture, it was stirred for three to four minutes. Steel fibers were introduced and rapidly.

**Table 4** Properties of used steel

| Grade | Min Yield stress (N/mm²) | Min elongation % at failure | Ductility degree | Weldability |
|---|---|---|---|---|
| B500CWR | 500 | 14 | C | no. |
| B500DWR | 500 | 13 | D | yes |
| B240D-P | 240 | 22 | D | no |

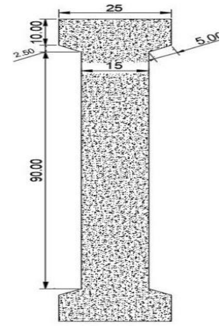


**Fig.3** Tested column

3.4 Testing procedures

3.4.1 Cubes specimens

A slump test was conducted in compatible with ASTM C143 (221) [43]. Cubes (150 mm × 150 mm x 150 mm) were tested to evaluate compressive strength, and ASTM 2020 was followed in the testing procedures [44].

3.4.2. Columns specimens

Six columns were used with dimensions of 150*250*1200 mm divided into three groups, Group 1

Consists of three columns CHR –CH1- CH2 reinforced with 10 mm as main reinforcement and 8 mm stirrups. Group2, consists of CH3 with 12 mm main reinforcement and 8mm stirrups. Group 3 consists of CH4 with 12mm main reinforcement and 8mm stirrups and CH5 with 10mm as main reinforcement and stirrups. The reinforcement bars were uniformly distributed around the perimeter. To avoid premature failure of specimens, the formworks of columns were hunched at its ends.

Concrete was mechanically pressed using external vibrator to ensure full compaction of concrete inside the forms. Table 5 and Figure 3 show all details and properties of tested column specimens and all information concerning cube compressive strength; fcu, at the time of testing.

**Fig.4** Strain gauge placement

3.4.2.2 Strain gauge placement

Two strain gauges have been mounted in each column. One was mounted on the middle of vertical steel bars, for all columns, while another one was mounted on the steel stirrups in two columns (CH1,CH5) as shown in figure 4.

The strain gauges used have resistance of 119.6 Ohms at 11ºC.The gauge factor ranges 2.11 ±1.0%.

**Table5** Details and properties of tested column

| Specimens No. | Fcu Actual (kg/cm²) | Steel fiber (kg/m³) | Transversal Reinforcement | | Longitudinal Reinforcement | Variables | Longitudinal Steel Grade |
|---|---|---|---|---|---|---|---|
| | | | Stirrup Steel Grade | Ast | As | | |
| **CHR** | 967 | ZERO | B240D-P | 8Ø8 | 4Ø10 | Reference | B500DWR |
| **CH1** | 1020 | 20 | B240D-P | 8Ø8 | 4Ø10 | Steel fiber content | B500DWR |
| **CH2** | 1015 | 40 | B240D-P | 8Ø8 | 4Ø10 | | B500DWR |
| **CH3** | 1020 | 20 | B240D-P | 8Ø8 | 4Ø12 | Main reinforcement with CH1 | B500DWR |
| **CH4** | 1020 | 20 | B240D-P | 8Ø8 | 4Ø12 | Grade of steel with CH3 | B500CWR |
| **CH5** | 1020 | 20 | B500DWR | 8Ø10 | 4Ø10 | Stirrups with CH1 | B500DWR |

3.4.2.3 Test setup

AMSELLER Hydraulic Compression Machine, with a 5000-kN capacity, was used to test the column specimens. Installing the tested column specimen vertically between the machine heads was the setup procedure for each test. In addition to adjusting the head bearing plates to avoid eccentricity from improper positioning or column head leveling, the machine heads ensured that the load eccentricity was maintained throughout the loading process. A broad perspective of the test setup is shown in Figure 5 and 6. Columns under test were loaded till they broke. The ultimate load capacity, concrete stresses, and steel reinforcement strains were noted for every tested column.


**Fig.5** Recording results

Strains were measured in the test zone of concrete for all tested columns specimens. The vertical strain in concrete of tested column specimens was measured with the use of LVDTs, or linear variable displacement transducers. As seen in figure 4, the data from the (LVDTs) were linked to the data acquisition system. The locations of (LVDTs) are displayed in figure5.

**Fig.6** The Position of LVDT

3.4.2.4 Test procedure

The tested specimens were placed between the machine heads and centered with its axis. Throughout the test setup, care was taken to ensure that the applied load was as concentrically as possible. The strain gauge wires were then connected to the data measuring devices. Although a rigorous procedure was followed for aligning the specimens, some eccentricities were unavoidable. Before loading, Steel strain measurements and vertical concrete displacement were both nil.

After turning on the pressure pump, the load was applied progressively up to the failure load, with increments of 100 kN. Steel stresses, concrete vertical displacement, and total applied load were noted at each load value. The whole unloading portion of the load-deformation curves proved challenging to acquire because of the loading system's characteristics. To trace the unloading portion of the curves, however, an attempt was made to manually operate the machine. Figure 7 displays the tested column and the test setup.


**Fig.7** Test set up of tested column

3.5 Strength and ductility measurements

3.5.1 Axial strength

Two methods were used to evaluate the column strength. The first method is defined as the ratio between the confined core strength fcc and the unconfined concrete strength fco , based on the concrete cube strength fcu. It is called the effective confinement [44].

3.5.2 Column ductility

According to Paultre and Legreon, ductility is defined as the ratio of the axial strain of the confined core at a particular loading level in the descending portion to the axial strain at maximum strength of the restricted core. This ratio is known as the axial strain ductility ratio. This study employed ductility measurements based on the confined core stress-strain curves [45]. The strain

ductility ratios were:

μ0.85Pu = ξ0.85Pu / ξcc ;

μ0.50Pu = ξ0.50Pu / ξcc ;

μ0.85f = ξ0.85f / ξcc ; and

μ0.50f = ξ0.50f / ξcc

Where:

μ0.85Pu = Axial strains ductility ratio corresponding to ξ0.85Pu ;

μ0.50Pu = Axial strains ductility ratio corresponding to ξ0.50Pu ;

μ0.85f = Axial strains ductility ratio corresponding to ξ0.85f ; and

μ0.50f = Axial strains ductility ratio corresponding to ξ0.50.

## 4. Results of fresh concrete

### 4.1 Slump and workability

The slump value for control mix (M1) was 200 mm, then it decreased to 180 mm, 160 mm, for M2, M3, respectively. Therefore, the decrease in slump values was about 10% for steel fiber content Vf=2%, 20% for Vf=4% .According to Sheikh, et al, slump of concrete decreased with increase in dosage of the steel fibers than conventional concrete[46].

Yu, R showed that when steel fiber fraction increased from 0.5% to 2.5%), relative slump flow reduced linearly. The following succinctly describes the primary cause of the decreased slump: When there is more steel fiber present, the steel fibers interlock and become less workable. Conversely, when the length of the fiber exceeds the size of the aggregate, the fiber's surface area increases and a cohesive force is created between the fibers [47].

### 4.2 Compressive strength

After 28 days of curing, the compressive strength of cubes samples in each group was measured as average of three cubes, and the results were illustrated in Table 6.

At a steel fiber dosage of 3%, compressive strength was found to be 15% to 34% greater than that of conventional and recycled aggregate concrete, according to Sheikh, I. et al. [48].

According to Yusef, S.M. et al., adding steel finer to high strength concrete at 1%, 2%, or 3% increased the concrete's compressive strength by 7.8%, 18.7%, or 10.5% after 28 days [49].

Steel fibers prevent concrete cracks from forming and spreading, which eventually leads to stronger concrete (Kumar et al.; Ibrahim et al,)[50,51]. When incorporating steel fibers in accordance with ASTM C109/C109M-07 [45] and ASTM C39/C39M-10 standards [53], Kazemi and Lubell [54] saw a favorable result. Researchers found that a higher fiber percentage enhanced peak strain in addition to compressive stress, indicating ductile behavior and changing the failure pattern Wang [54].

At 0.5, 1.0, and 1.5% fiber content, the compressive strength of a concrete reinforced with hook steel fibers improved by 1.41, 11.52, and 20.81%, respectively, as reported by Salman and Rafea. On the other hand, for the same percentages of steel hooked fiber, the compressive strength of a concrete reinforced with straight steel fibers improved by 7.27, 20%, and 21.4%. Because it prevents cracks from growing worse, the concrete's ultimate compressive strength improved [55, 56].

According to bond strength of mixture and steel fiber. by passing through the growing microcracks at the gravel-mortar contact, steel fibers might strengthen the concrete. In the samples of fiber-armed concrete, the failure happened gradually, whereas in the samples of regular concrete, it happened suddenly [57].

According to research by Mujalli et al., adding up to 2% of steel fibers to concrete mixes can greatly increase the concrete's compressive strength by around 20%.By raising the fiber volume percentage to 11%, a stronger link was formed between the fibers and the matrix interface, which resulted in an increase in compressive strength [58].

According to Huawei Yin and Yaoguo Ouyang, the strength of steel fiber-reinforced concrete modestly increases as steel fiber percentage rises (within 2%) [59].

**Table 6** Summary of slump test results for tested columns

| Specimens No. | CH1 | CH2 | CH3 | CH4 | CH5 |
|---|---|---|---|---|---|
| Fcu Actual (MPa) | 102 | 101.5 | 102 | 102 | 102 |
| Slump (cm) | 18 | 16 | 18 | 18 | 18 |

### 4.3 Ultimate and cracking loads

Table 7 shows the ultimate and cracking load for all tested columns. It was observed that presence of steel fiber increased the percentage of yield load to ultimate load from 0.829 to 0.85.

**Table 7** Ultimate and yield load for tested columns

| Specimen | Yield Load Py (kN) | Ultimate Load Pu (kN) | Py / Pu |
|---|---|---|---|
| CHR | 1047.2 | 1263.8 | 0.829 |
| CH1 | 825.66 | 971.4 | 0.85 |
| CH2 | 780.86 | 918.7 | 0.85 |
| CH3 | 864 | 1016.55 | 0.85 |
| CH4 | 899.27 | 1057.97 | 0.85 |
| CH5 | 920.61 | 1083.1 | 0.85 |

## 5. Results of studied factors

This next subsections include an analysis of the impact of the primary test factors on the behavior of the examined columns. This analysis takes into account the stirrups ratio, percentage of steel fiber, longitudinal steel grade, and longitudinal reinforcement ratio as variables.

5.1 Effect of ratio of longitudinal steel

The examined columns' performance under loading was significantly impacted by variations in longitudinal steel. Table 8 shows the strain in steel and concrete at yield load for columns CH1 and CH3, it was found that increasing longitudinal steel from 4Ø10 to 4Ø12 increases the ultimate load and strain in steel at ultimate load by nearly 5% and 22.6%, respectively. While it decreased strain in concrete at yield load by 36%.

The ultimate stress on the column increased as a result of the increased length of longitudinal steel. The specimens with polypropylene fibers showed a gain in core strength of 41.96% and an increase in column ultimate load of 35.74% when the amount of steel was increased from 4Ø12 to 8Ø16. In contrast, the specimens with steel fibers showed a gain in core strength of 65.72% and an increase in column ultimate load of 38.91% [60].

According to Sotoud and Aboutaha [61], the longitudinal reinforcement ratio for RC columns is practically between 1% and 4%.

Results by Rafaa and Akram demonstrate that raising the longitudinal reinforcement ratio from 1% to 3.2% for axial load indices of 0.1, 0.2, and 0.4, respectively, results in a decrease in the ultimate drift ratio and a rise in the peak lateral force (144%, 116%, and 78%) as well as the flexural strength (129%, 105%, and 67%) [61].

The impact of raising the longitudinal steel on the yield load was examined by Tingting et al. They discovered that the axial bearing capacity rose in proportion to the longitudinal reinforcement ratio. The column specimen's axial compression bearing capacity and strain were somewhat impacted by the longitudinal reinforcement ratio [62].

According to Feiyan Zhang et al., as the reinforcement ratio increases, the ductility of the column section decreases.The ductility drops by around 58% for small eccentricity and by roughly 70% for big eccentricity as the reinforcement ratio rises from 0.34% to 1.23% [63].

In contrast, when the percentage of vertical reinforcement was increased from (0.18% up to 0.73%) at the same stirrup percentage, the percentage of the ultimate failure load increased by approximately 4.1% from the experimental results, according to Kamal . This represents a 5.7% increase in the ultimate failure load percentage from the finite element analysis. As transversal reinforcement rises, so does the potential for ultimate strength [64].

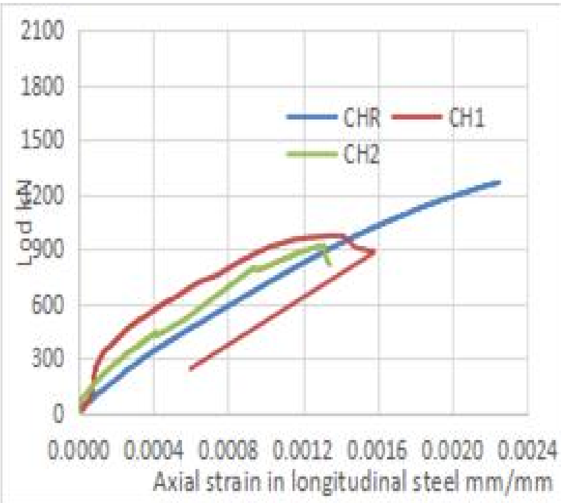


**Fig.9 Relation** between load and strain in columns

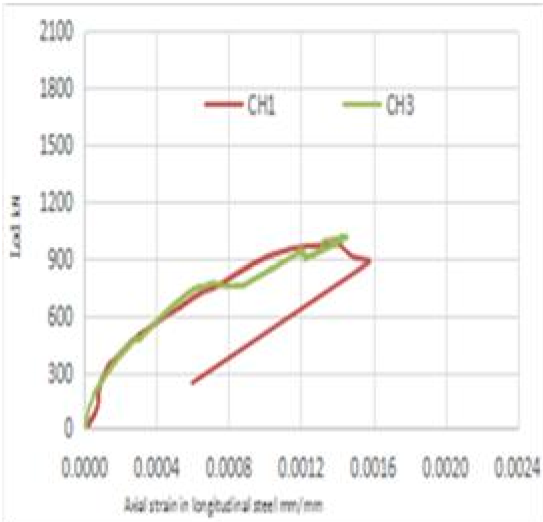


**Fig. 10** Relation between load and strain in columns CH4 and CH3

Table 8 The results of strain in steel and concrete in CH1,CH3

| Specimen | Main reinforcement | Ultimate Load Pu | | Strain int steel at Yield Load | | Strain in Concrete at yield Load | |
|---|---|---|---|---|---|---|---|
| | | (kN) | Percentage of CH1 | Mm/mm | Percentage of CH1 | Mm/mm | Percentage of CH1 |
| CH1 | 4Ø10 | 971.4 | 100% | 0.0084 | 100% | 0.00122 | 100% |
| CH3 | 4Ø12 | 1016.6 | 104.6% | 0.00103 | 122.6% | 0.00078 | 64% |

Table 9 Results of strain in steel and concrete

| Specimen | Steel fiber (Kg/m3) | Ultimate Load Pu | | Strain in Steel at Yield Load | | Strain in Concrete at yield Load | |
|---|---|---|---|---|---|---|---|
| | | (kN) | Percentage of CHR | Mm/mm | Percentage of CHR | Mm/mm | Percentage of CHR |
| CHR | 0 | 1263.79 | 100.0% | 0.00175 | 100.0% | 0.00114 | 100.0% |
| CH1 | 20 | 971.37 | 77% | 0.00084 | 48% | 0.00122 | 107% |
| CH2 | 40 | 918.66 | 73% | 0.00089 | 50.8% | 0.0006 | 52.6% |

5.2 Effect of main steel grade

The ultimate load and strain in steel and concrete at yield load was recorded in table10 and represented in figure 11.

Column CH3 and CH4 have the same main steel area but they differs in steel grade. CH4 has higher ductility than B500DWR.Comparing column CH3 and CH4 it was found that changing grade of main steel led to increase in ultimate load by around 5%, while the strain in steel and concrete at yield load decreased by 48.5% and 10%, respectively.

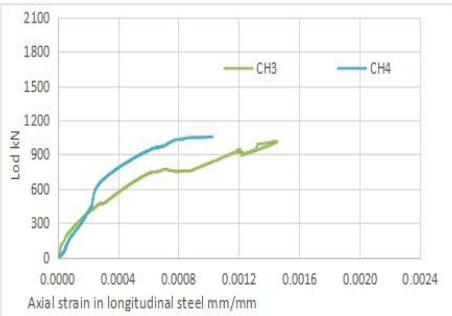


**Fig.11** Load axial strain in columns CH3, CH4

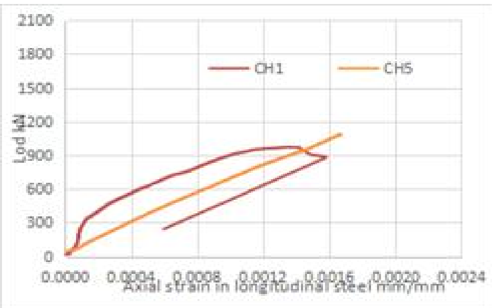


**Fig.12** Load axial strain of CH1 and CH5

Ángel et al, concluded that depending on the results obtained, it is verified how the inclusion of steel-fibers produces notable improvements in ductility [65].

5.3 Effect of steel fiber content

Comparing the behavior of CHR (the reference column), CH1 column with steel fiber 20Kg/m$^3$, and CH2 column with steel fiber content 40Kg/m$^3$ as indicated in Table 11and Figure 12, it was observed that increasing steel fiber content decreased the ultimate load of column and the strain in steel. Strain in concrete decreases as the steel fiber content increased to 40kg/m$^3$, while it increased in column CH1 which has 20kg/m$^3$ steel fiber content.

The impact of adding steel fiber to HSC columns solely through the concrete cover area was investigated by Hadi . The addition of 1, 1.5, and 2% steel fiber content, respectively, resulted in a negligible increase in the ultimate load, according to the experimental axial testing on the columns. In contrast to fully-fiber columns, the ductility of columns with steel fiber content in the outer concrete cover only [66].

Al-Taan and AlDoski, discovered that steel fibers had a dominating influence in lowering the strain in the concrete and steel reinforcement. Based on the experimental test results, the strain in concrete dropped by 52% at steel fiber contentof 20 kg/m$^3$ under the same residual circumstances. This result was consistent with the findings [67].

To study this parameter, two columns were cast and tested. The results were concluded in table 11 and figure 11. Columns CH1 and CH5 have the same main reinforcement and the same steel grade but differs in stirrups diameter as CH1 has stirrups of 8Ø8, while CH5 has 8Ø10. Comparing the strain in steel it was found that, increasing stirrups percentage increased the ultimate load of column by 11.5%. Increased the strain in steel and in stirrups by 76 and 50%, respectively.

Abdelhamid and Owida looked at how the quantity of stirrups affected a column's ability to support an axial load. The findings demonstrate that when the proportion of stirrups densification height at the top and bottom of the column / total column height increases, the failure load also increases [68].

When compared to RC members without or with inadequate shear reinforcement, steel stirrups significantly enhance the shear performance of RC members. In addition to bearing the increase in shear strength during the postcracking phase, steel stirrups are crucial in preventing the abrupt diagonal fractures that form in concrete (Van et al., ; Lu et al., ; Khattab et al., [69,70,71].

According to Kamel, the percentage of ultimate failure load increased by 11.8% in the experimental results when the percentage of stirrups increased from ρ v = (0.27% up to 1.09 %) at the same vertical reinforcement percentage, whereas the percentage increased by approximately 12.3%

With a rise in the volume stirrup ratio, the composite column's deformation performance improved and the compressive strain corresponding to the relevant load rose.It is evident that there is some relationship between the volume stirrup ratio and the related compressive strain and yield load of High Performance Fiber Reinforced Compacting Concrete specimens.According to Bai et al. [72], there was a 10.63% increase in yield load of ECCT-02 when compared to ECCT-01.

A linear increase in the beginning strain was the effect of varying volume stirrup ratios on the axial load−longitudinal reinforcement strain curve, and the general development law of the curve was essentially the same. Early in the loading process, the longitudinal reinforcement stresses gradually rose. The strain growth rate of the stirrup was much higher when the axial load reached 80% of the peak load. It is evident that as the volume stirrup ratio grew, each specimen's peak load progressively rose and the longitudinal reinforcement was more strongly restrained, causing the specimen to yield later. Additionally, the specimen's capacity to deform was improved.

in the analytical results.Increasing the stirrups volumetric ratio results in a more ductile RC column with less brittle failure. 4. The stirrups effectively increase the ultimate load capacity when used with vertical steel bars. Therefore, while designing RC columns, the role of stirrups, vertical steel bars, and concrete should be taken into account [64].

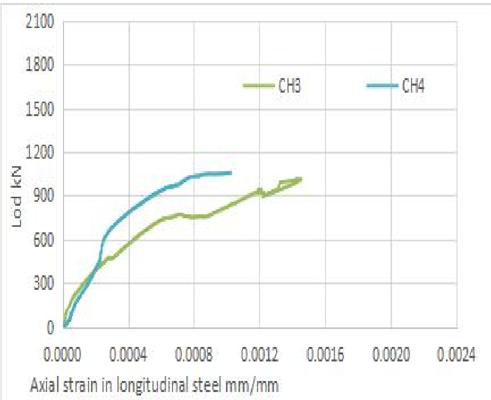


**Fig.11** Load and strain in columns CH3, CH4

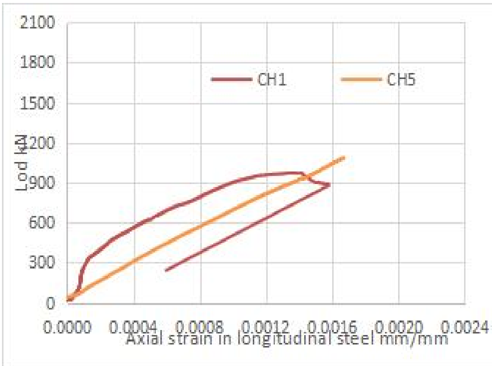


**Fig.12** Load axial strain in columns CH1,CH5

**Table 11** The results of strain in steel and concrete

| Specimen | Main reinforcement | Ultimate Load Pu | | Strain in Steel at Yield Load | | Strain in Concrete at yield Load | |
|---|---|---|---|---|---|---|---|
| | | (KN) | Percentage of CH3 | Mm/mm | Percentage of CH3 | Mm/mm | Percentage of CH3 |
| **CH4** | B500CWR | 1057.97 | 104.6% | 0.00053 | 51.4% | 0.0007 | 90% |
| **CH3** | B500DWR | 1016.6 | 100% | 0.00103 | 100% | 0.00078 | 100% |

**Table12**: The results of strain in steel and concrete

| Specimen | Stirrups /m | Ultimate Load | | Strain in Steel at Yield Load | | Strain in Concrete at yield Load | |
|---|---|---|---|---|---|---|---|
| | | Pu-kN | %of CH1 | Mm/mm | % of CH1 | Mm/mm | %of CH1 |
| **CH1** | 8Ø8 | 971.37 | 100% | 0.00084 | 100% | 0.00028 | 100% |
| **CH5** | 8Ø10 | 1083.1 | 111.5% | 0.00148 | 176.1% | 0.00042 | 150% |

## 6 Failure mode

A different column failure modes exists with higher concrete compressive strength. Failure modes for columns are presented in Figure. 13. The failure for column specimen CHR which is the reference column was in the middle third of the height. Failure was induced at about half of the spacing between the adjacent stirrups, due to the greatest free lateral strain of concrete. The specimens CH1 CH4,and CH5, the failure has happened in the upper third of the column height. While columns CH2 and CH3, the failure has happened in the column head. That may be led to insufficient stirrups in the head.

In comparing column failure mode with respect to the longitudinal steel content (CH1 and CH3), more sever column spalling was observed in specimens with large steel ratio (CH3).CH2 has highest steel fiber content, but not distributed regularly which caused failure

## 7 Conclusions

This paper examined how the behavior of a high strength concrete column under axial compression was affected by the ratios of longitudinal steel, stirrups diameter, main steel grade, and steel fiber content. Based on the experimental results of this study, the following conclusions have been drawn:


**Fig.13** Failure mode

Effect of ratio of Longitudinal Steel : increased amount of longitudinal steel caused an increase in ultimate load (about 5% increase in CH3 compared to column CH1, an increase tension strain in main steel at yield load by 22.6% in column CH3 compared to CH1, while the compression strain in concrete decreased in column CH3 by 36% compared with CH1 ).

Effect of Main Steel grade: Comparing CH3 with B500DWR and CH4 with B500CWR, it was found that: ultimate load in CH4 increases more than CH3 by about 4%. Tension strain in steel at yield load in column CH4 was 51.4% of tension strain in CH3, while compression strain in concrete decreased by 10% in column CH4 compared to column CH3.

Effect of Steel fiber content: comparing column CHR, CH1, and CH2, it was found that; adding steel finder led to a decrease in ultimate load and strain in steel.

Effect of Stirrups Diameter: column CH1has stirrups 8Ø8/m while column CH5 has stirrups 8Ø10/m. it was found that ultimate load, tension strain in main steel at yield load, and compression strain in concrete increase as the stirrups diameter increased.

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