International Journal of Emerging Research in Engineering, Science, and Management
Vol. 4, Issue 2, pp.32-39, Apr-Jun 2025.
www.ijeresm.com eISSN – 2583-4894

Axial Compression Behaviour of Steel Square Column Filled with Steel Fibre Concrete

[1]Prakash K.C., [2]N. Siva Kumar, [3]Korakuti Hanumanthu

[1]PG Scholar, Department of Civil Engineering, Bonam Venkata Chalamayya Engineering College (Autonomous), Odalarevu, India. kcprakash652@gmail.com
[2,3]Associate Professor, Department of Civil Engineering, Bonam Venkata Chalamayya Engineering College (Autonomous), Odalarevu, India.
[2]shiva3118@gmail.com, [3]hanu.korakuti@gmail.com

Abstract: Steel Fibre Concrete-Filled Steel Square Tubes (SFCFSST) represent a modern and highly efficient structural system that combines steel's strength and enhanced fibre-reinforced concrete performance. These columns exhibit improved compressive strength, ductility, and overall structural integrity by integrating steel fibres and expansive agents into the concrete mix. Although using such composite columns remains a relatively new concept, their potential to enhance seismic resistance, load-bearing capacity, and fire resilience positions them as a promising solution for future construction practices. In this study, axial compression tests were completed. According to the test results, the axial compression behaviour of columns increases with the proportion of steel fibres replaced. It has higher ductility than regular Concrete Filled Steel Tubes (CFST) columns. In this article, the strength attributes of CFST structures were investigated utilising Steel Fibre in various proportions, i.e., 0%, 0.5%, 1%, 2%, and 3% as partial replacements for Coarse Aggregate.

Keywords: Axial Compression, Compression Strength, Concrete-Filled Steel Tubes, Steel Fibre.

1 INTRODUCTION

Concrete-Filled Steel Tube columns provide excellent structural performance, including high load-bearing capacity, seismic resistance, and fire protection. Incorporating steel fibre-reinforced concrete enhances ductility and helps control crack propagation. For columns under pure compression, high-strength concrete and thicker steel tubes are more effective than relying on higher-yield-strength steel. Combining expanding agents with steel fibres significantly increases the axial compression performance of circular CFSTCs [1]. These enhancements include increased compression strength, improved ductility, and better strain behaviour. Monitoring during curing confirmed the positive effects of expansion on long-term performance. Overall, incorporating expansive agents and steel fibres is an effective strategy for addressing concrete shrinkage and enhancing the structural behaviour of CFST columns in demanding applications like bridges and high-rise buildings.

The contact force between the concrete and the steel tube rapidly diminishes from compressive to tensile [2]. The critical buckling stress and elastic stiffness of the column are unaffected by the strength of the glue between the concrete and the steel tube. A steel tube under longitudinal tension has no transverse confinement impact on the concrete because the longitudinal and transverse strains at a point are opposed. Steel fibre-reinforced concrete-filled steel tube columns have much better compressive strength and stiffness due to the steel tube's confinement effect and the inclusion of steel fibres [3]. The strength and stiffness of the composite column are greatly impacted by the choice of steel fibre-reinforced concrete as an infill material. Increasing the quantity of steel fibre in concrete significantly increases the ultimate strength and durability of the columns, according to the nonlinear finite element model created to investigate the flexural behaviour of steel fibre-reinforced concrete-filled steel tube columns [4]. The study found that adding steel fibres (up to 4%) increased the flexural strength by about 30% for short columns and 50% for long columns.

The Carbon Fibre reinforced polymer (CFRP)-steel tube provides effective confinement from the early loading stages [5]. In contrast, the initial stress in the steel tube slightly delays the interaction with concrete without significantly affecting peak performance. Furthermore, the adhesive strength between materials had minimal impact on compression behaviour. Including an inner Carbon fibre reinforced polymer circular tube significantly improves the ductility and load-bearing performance of the columns under axial compression [6]. The CFRP tube effectively confines the innermost concrete, allowing it to carry more load, especially after reaching the ultimate capacity. High shear-span ratios led to bending failure, while lower ratios caused bending-shear failure [7]. An increase in shear-span or diameter-thickness ratios reduced the peak moment, whereas peak curvature was mainly affected by the axial compression and shear-span ratios. The diameter-thickness ratio and expansion rate do not affect peak curvature. Understanding the structural behaviour of self-stressing steel slag aggregate concrete-filled steel tubular (SSACFST) columns can guide their design for greater seismic performance. Recycled coarse aggregate (RCA) reduces the axial bearing capacity of concrete-filled steel stub columns; this effect can be offset by increasing steel fibre content and concrete strength [8].

International Journal of Emerging Research in Engineering, Science, and Management
Vol. 4, Issue 2, pp.32-39, Apr-Jun 2025.
www.ijeresm.com eISSN – 2583-4894

Steel fibres enhance bearing capacity, though the rate of improvement decreases at higher fibre content. Concrete strength plays a significant role in improving stiffness but reduces ductility significantly, whereas steel fibres have a more minor impact on ductility. Both concrete strength and steel fibre content contribute to increased stiffness, highlighting their importance in optimising the performance of steel fibre-reinforced RCA concrete-filled columns. Higher Concrete strength has no bearing on deflection behaviour [9]. However, length-to-diameter ratios and RCA replacement ratios reduce stiffness and increase deflections. Reducing the length-to-diameter ratio and RCA replacement ratio while improving concrete strength is the most efficient method of enhancing bearing capacity.

Therefore, in recent years, steel fibres have gained popularity as a construction material due to the depletion of natural resources [10]. They were introduced to address the limitations of conventional reinforcement methods like steel bars or mesh. CFST columns are a new civil construction idea noted for their high strength and exceptional ductility performance. The increasing demand for construction materials due to social development emphasises the importance of developing alternatives to scarce natural resources. CFST columns are made of concrete poured into a steel tube, which allows the materials to work together to withstand external loads and increase structural strength. Steel fibres are commonly used in various concrete structures, such as bridge panels, industrial floors, and precast concrete slabs. When added to concrete, steel fibres distribute strain across cracks, improving ductility, tensile strength, and impact resistance. Their inclusion also provides crack control and prolongs the service life of concrete. In tunnelling applications, steel fibres enhance concrete's strength and crack resistance during drying [11][12].

The primary applications of Steel Fibre Reinforced Concrete include industrial buildings, floors, and crack control joints. Its use has expanded in the construction industry as it can significantly enhance the durability of structural components when properly mixed and cast. The properties of steel fibres, such as aspect ratio and diameter, influence the performance of concrete. Research indicates that incorporating steel fibres into concrete in precise proportions increases compression strength and improves crack control. However, little research has been undertaken on the effects of different steel fibre doses, emphasising the need for additional research. So, this work attempts to investigate the axial compression behaviour of a steel square column filled with steel fibre concrete. The influence of curing times (7, 14, and 28 days) on engineering properties was investigated. Introducing steel fibres as an aggregate replacement in steel tubes or columns—referred to as Steel Fibre-Filled Steel Square Columns (SFFSSC)—can improve the strength of these members and enhance crack control in concrete [13][14].

2 Materials and Methodology

2.1. Materials

Because it holds sand and aggregates together, cement is a crucial binding ingredient in building and is essential to creating concrete. Sarbottam's OPC 53-grade cement, which has a typical consistency of 30%, was utilised for this job. The quality and performance of concrete are greatly influenced by fine aggregate, affecting the material's strength, durability, and affordability. A grading zone helps us determine the fine aggregate. River sand from Zone II was used in this work. Coarse aggregate is a key component of concrete, contributing to approximately 60-65% of the mix and enhancing its structural rigidity. Coarse aggregates also help minimise shrinkage and reduce surface cracking, making them an integral part of high-quality concrete. In this research, angular coarse aggregates of 20mm were used. Water is a crucial ingredient in concrete production, enabling the chemical hydration process that binds aggregates together and hardens the mix.

A water-cement ratio of 0.45 was used in this work. Steel fibres are an effective form of secondary reinforcement in concrete, offering improved resistance to cracking, impact, fatigue, and bending. By creating a uniform reinforcement network throughout the concrete, steel fibres enhance its tensile strength, durability, and post-crack performance. Steel fibres are 0.8 mm in diameter and 20-25 mm long. CFST columns are increasingly used in composite construction. The steel tube contains the infill concrete and supports axial force during compression. The confinement provided by the steel tube contributes significantly to the high axial strength of CFST columns. The interaction of the steel tube and concrete is one of the key advantages of a CFST column. A square steel section was sourced from a local iron grill shop. The steel tube has a required diameter of 91.6 mm. The steel column's specifications are 500 mm long and 2.5 mm thick.

2.2. Methodology

To fulfil the research objectives, this study was carried out in two main stages: a desk-based study followed by laboratory experimentation. Each phase played a crucial role in shaping the overall investigation.

Desk-Based Study

The first phase focused on understanding the existing research landscape. An extensive review of scholarly literature was conducted to gather insights into the behaviour of steel fibre-reinforced concrete and steel fibre concrete-filled steel square columns (SFCFSST). This review helped identify key research gaps and shaped the direction of the experimental program.

Laboratory-Based Study

This included the preparation of steel fibre, selection and testing of materials, and casting of test specimens. This included the preparation of steel fibre, selection and testing of materials, and casting of test specimens. The primary tasks carried out during this stage are listed below:

- Sourcing and preparation of materials, including manufactured steel fibres
- Testing of material properties
- Designing concrete mix proportions
- Conducting workability tests
- Curing of specimens
- Carrying out strength tests

Two types of specimens were prepared to evaluate the performance of steel fibre concrete: conventional concrete cylinders (referred to as the *CC series*) and steel tubes filled with steel fibre concrete (the *SFCFSST series*). Tables 1 and 2 present the detailed mix proportions used in each case.

Table 1. Mix Proportions of Cement Concrete Specimens

Mix ID	Cement (kg/m³)	Fine Aggregate (kg/m³)	Coarse Aggregate (kg/m³)	Steel Fibre (% replacement of Coarse Aggregate)	Steel Fibre (kg/m³)	Water-Cement Ratio
CCNAS	400	650	1200	0%	0	0.45
CC0.5SF	400	650	1194	0.5%	6	0.45
CC1SF	400	650	1188	1%	12	0.45
CC2SF	400	650	1176	2%	24	0.45
CC3SF	400	650	1164	3%	36	0.45

Table 2. Mix Proportions of Steel Fibre Concrete Used in SFFSST Specimens

Specimen ID	Steel Tube Size (mm)	Cement (kg/m³)	Fine Aggregate (kg/m³)	Coarse Aggregate (kg/m³)	Steel Fibre (% replacement)	Steel Fibre (kg/m³)	Water-Cement Ratio
SFFSST0.5	100 × 100 × 600	400	650	1194	0.50%	6	0.45
SFFSST1	100 × 100 × 600	400	650	1188	1%	12	0.45
SFFSST2	100 × 100 × 600	400	650	1176	2%	24	0.45
SFFSST3	100 × 100 × 600	400	650	1164	3%	36	0.45

3 Results and Discussion

This section presents a detailed analysis of the experimental findings from axial compression tests on square steel tubes filled with steel fibre-reinforced concrete (SFFSST). The results emphasize the role of varying steel fibre content in influencing the structural and mechanical properties of the composite columns. Parameters such as workability (slump), compressive strength of standard cubes, axial performance of columns, stress–strain behaviour, deformation characteristics, and failure mechanisms are critically examined.

3.1. Slump Test Results

Slump tests were conducted to assess the workability of concrete with varying steel fibre content. Fig. 1 illustrates the variation in slump values for mixes containing 0% to 3% steel fibres. It was observed that the addition of fibres led to a marginal increase in slump, indicating a slight improvement in workability. This can be attributed to the lubricating effect of the smooth, elongated steel fibres within the matrix, which facilitated better particle movement. However, at higher fibre contents, slight segregation tendencies were noticed, which could impact mix uniformity if not controlled. The effectiveness of mixing procedures and uniform dispersion of fibres are crucial to maintaining consistency in such mixes.

3.2. Cube Test Results

Compressive strength testing of concrete cubes was conducted after curing periods of 7, 14, and 28 days. The samples were tested using a calibrated compression testing machine under standard loading conditions. As shown in Fig. 2, the compressive strength increased progressively with curing age and fibre content. This improvement is attributed to the bridging action of the steel fibres, which restricts the initiation and propagation of microcracks. Furthermore, fibre reinforcement enhances post-cracking strength and ductility. The improvement in early-age strength also indicates the potential of SFFSST in rapid construction applications, where early strength gain is desirable.

3.3. SFFSST Test Results

Axial compression tests on 46 SFFSST column specimens were conducted using a Universal Material Testing machine. All specimens were subjected to concentric loading. The failure loads recorded at different curing ages are presented in Fig. 3. Results clearly demonstrate that columns with higher steel fibre content show significant improvement in axial load-carrying capacity. The steel tube confinement and internal fibre bridging effect synergistically enhance strength and delay the onset of buckling. The inclusion of steel fibres increases the energy absorption capacity of the system, thereby improving both peak load and post-peak behaviour, which is essential in seismic or impact-resisting structures.

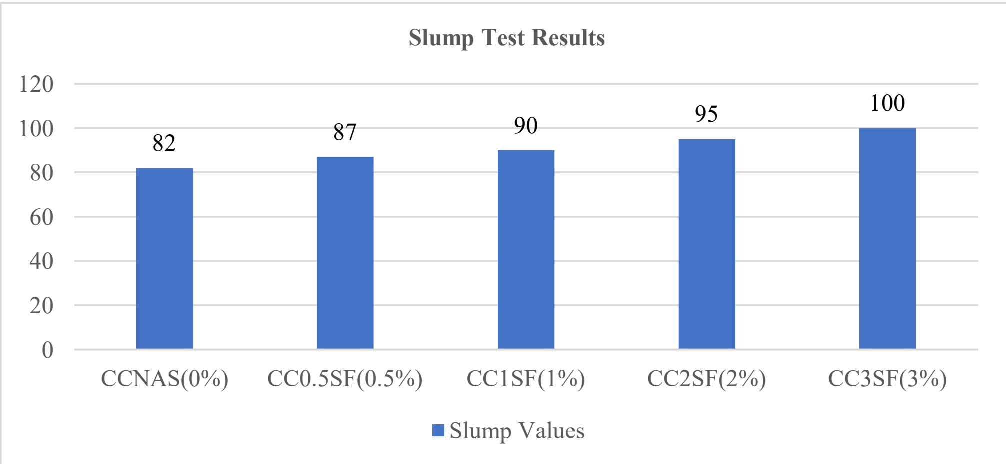

Fig. 1. Slump test results for different concrete mixes

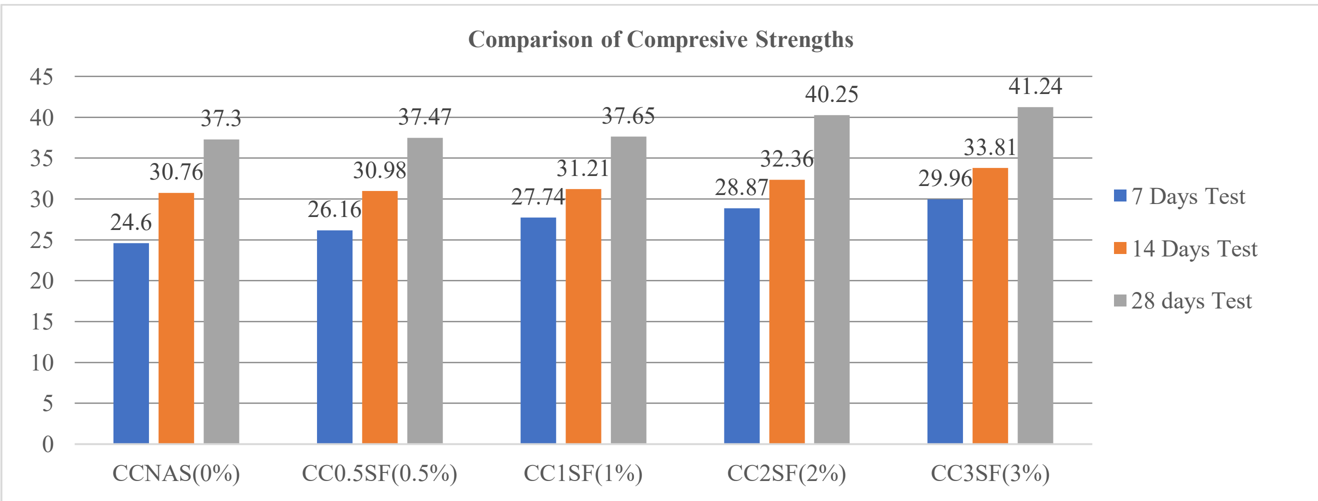

Fig. 2. Compressive strength of steel fibre-reinforced cubes at 7, 14, and 28 days

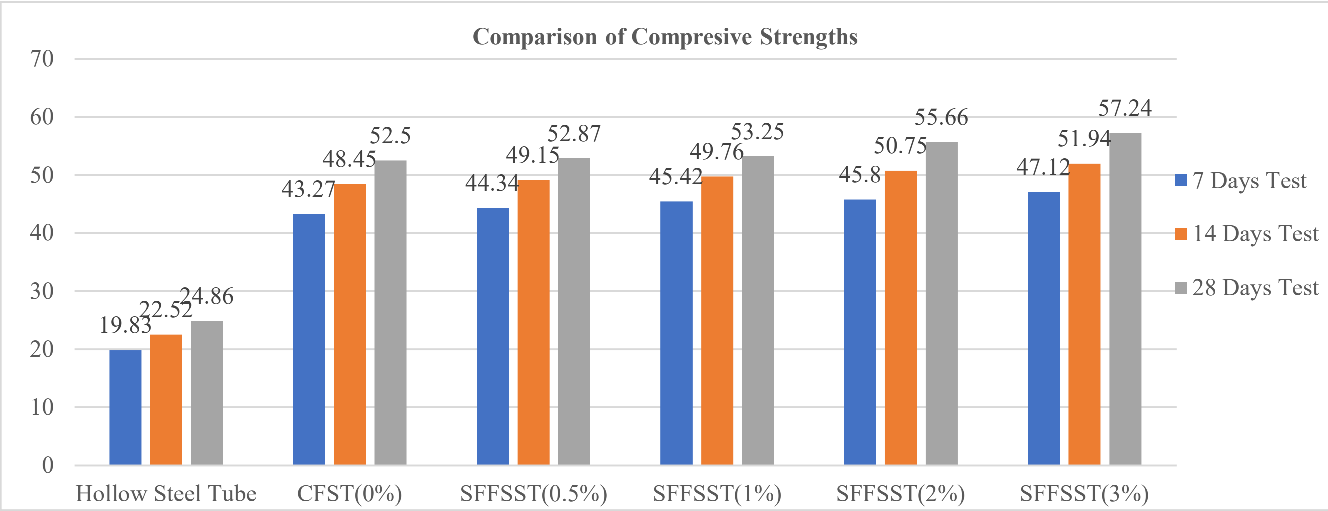

Fig. 3. Compressive strength of SFFSST columns at 7, 14, and 28 days

3.4. Comparison between Concrete Cubes and SFFSST Columns

3.4.1. Percentage Increase in Strength in Concrete Cubes

Table 2 quantifies the percentage gain in compressive strength for cubes containing different fibre contents compared to the control mix (0%). The data show a linear increase up to 2% fibre content and a slightly diminishing return at 3%, suggesting an optimal range around 2% for maximum efficiency in terms of cost-to-performance ratio. Fibre clustering at higher concentrations may explain the plateau in strength gains.

Table 2. Percentage increase in compressive strength of concrete cubes

S. No.	Average Strength (N/mm^2)	% Increase in Strength	Annotations
1	37.3	0.0	CCNAS (0%)
2	37.47	0.46	CC0.5SF (0.5%)
3	37.65	0.92~1	CC1SF (1%)
4	40.25	8	CC2SF (2%)
5	41.24	10.56	CC3SF (3%)

3.4.2. Percentage Increase in Strength in SFFSST Columns

As indicated in Table 3, the compressive strength of SFFSST columns significantly surpasses that of hollow CFST columns. The increase is more pronounced at higher fibre contents, which validates the composite action between steel tubes and fibre-reinforced concrete. This combination results in improved confinement, reduced lateral deformation, and enhanced ductility, making SFFSST columns a promising alternative in modern structural systems.

Table 3. The percentage increases in the strength of cubes

S. No.	Average Strength (N/mm^2)	% Increase in Strength	Annotations
1	52.2	0.0	CFST (0%)
2	52.87	1.28	SFFSST (0.5%)
3	53.25	2.01	SFFSST (1%)
4	55.66	6.62	SFFSST (2%)
5	57.24	9.65	SFFSST (3%)

3.5. Stress-Strain Curve

Fig. 4 presents the stress–strain response of SFFSST columns with varying fibre contents. The initial linear portion corresponds to elastic behaviour, followed by a nonlinear region representing strain hardening due to confinement effects.

Notably, the slope of the descending portion decreases with increasing fibre content, indicating improved ductility and energy dissipation. These curves provide critical insights into the deformation capacity and resilience of the columns under loading.

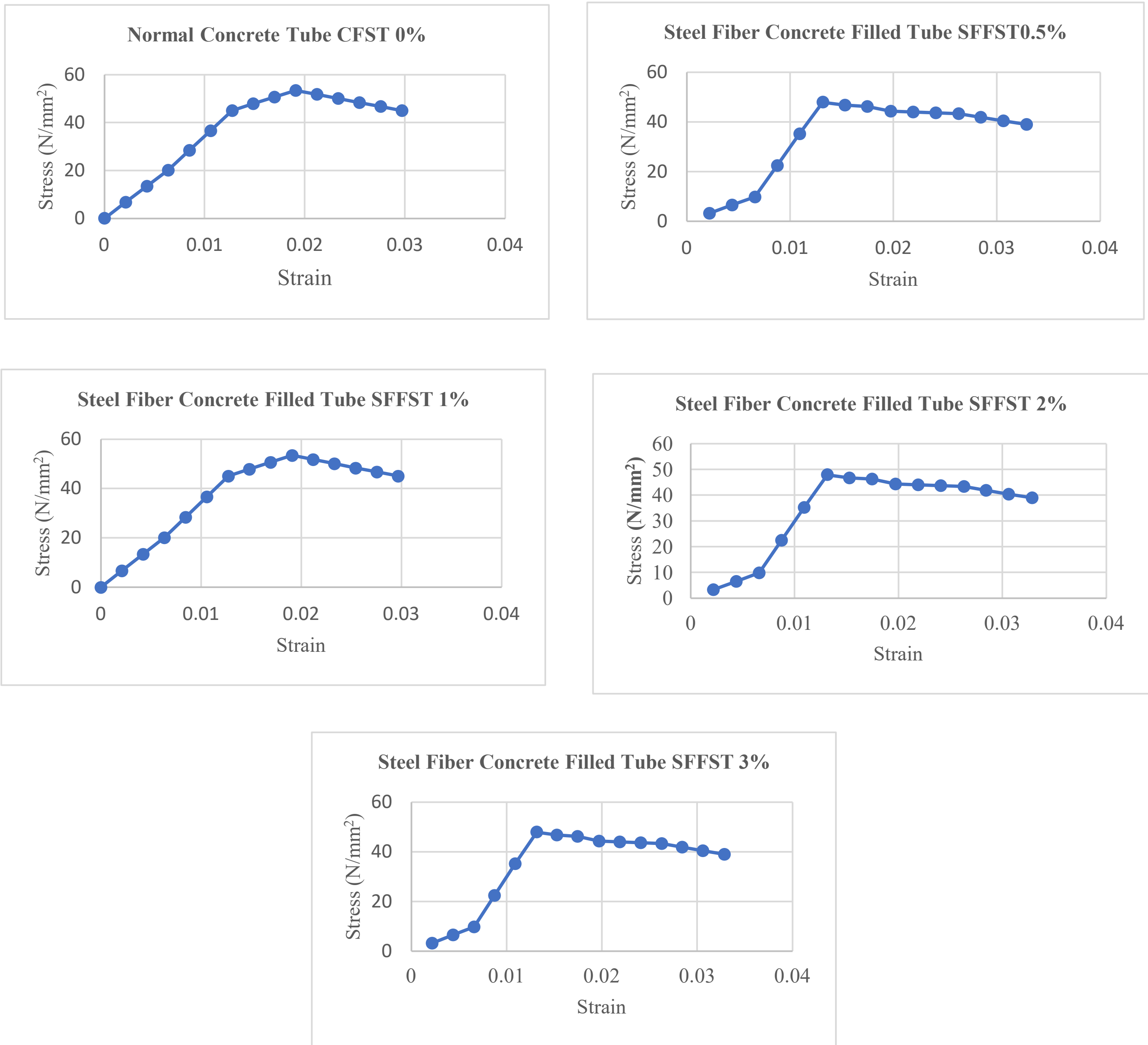

Fig. 4. Stress–strain curves of SFFSST columns

3.6. Deformation in Steel Tubes

Deformation analysis showed that increased steel fibre content led to greater ultimate displacements. The spacing between the yield and ultimate points increased, confirming improved ductile behaviour. Visual observations revealed that columns with higher fibre content developed fewer and narrower cracks, supporting the idea that fibre reinforcement distributes stress more evenly and delays local failure. These findings highlight the potential of fibre reinforcement in enhancing structural integrity under overload conditions.

3.7. Different Failure Modes of SFFSST Column

Post-failure observations revealed several types of column failure mechanisms, including:

- Shear failure, characterized by diagonal cracking and sliding planes.
- Bending failure, marked by flexural cracks due to insufficient lateral restraint.

International Journal of Emerging Research in Engineering, Science, and Management
Vol. 4, Issue 2, pp.32-39, Apr-Jun 2025.
www.ijeresm.com eISSN – 2583-4894

- Bulging (gross failure), attributed to outward deformation of the steel tube, is often observed in columns with lower fibre content.

Fig. 6 displays examples of these failure modes. The type and severity of failure were found to correlate with the fibre content, where higher fibre percentages helped delay and reduce the severity of localized failures. These observations affirm the importance of optimizing fibre volume for balanced strength, ductility, and durability.

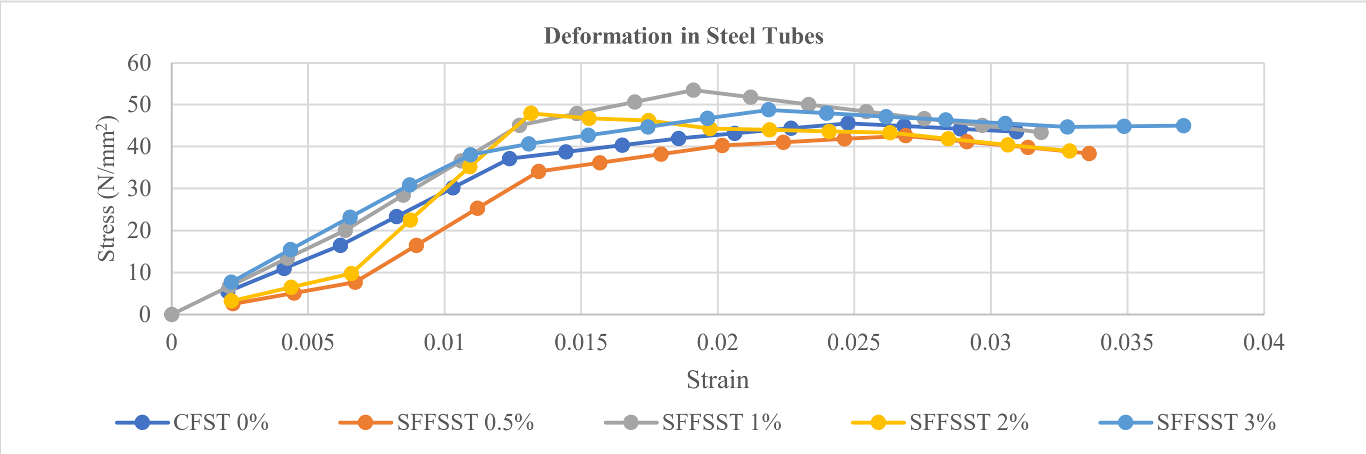

Fig. 5. Deformation – Stress vs Strain Curve

Fig. 6. Failure modes observed in SFFSST columns

4 Conclusions

This study presents fresh information on the behaviour of concrete-filled steel tubes containing steel fibre as a partial replacement for coarse aggregates. Based on experimental investigations, this research yields the following findings:

- By partially substituting steel fibre for coarse aggregate, fresh concrete becomes more workable. The higher the steel fibre content, the greater the gain in workability.
- Concrete's compressive strength improved when steel fibre was added. The compressive strength increases in tandem with the percentage of steel fibre.
- The results show that replacing natural aggregates with steel fibres improves the strength of both concrete cubes and SFFSST columns, with higher replacement ratios leading to greater strength gains. The most significant strength improvement was observed at a 3% replacement level. Additionally, the use of steel tubes in concrete helps prevent strength loss. It ensures the full utilisation of the concrete's potential strength, making it a practical approach for enhancing structural performance.
- The addition of steel tubes in concrete, such as in SFFSST (composite columns), can boost compressive strength by 1.3 to 1.4 times compared to concrete cubes, according to experimental data comparing M25 grade concrete strength over 28 days. The confinement effect provided by the steel tube is responsible for this steady improvement across a range of steel fibre replacement ratios, greatly enhancing the concrete's structural performance.

- Comparing the strength of steel square columns without cement concrete and with cement concrete after 28 days of curing clearly shows that filling steel square tubes with concrete significantly increases their compressive strength, by approximately 2.63 to 2.88 times, compared to hollow steel tubes. This strength increase is due to the composite action of the steel tube and the concrete core, in which the steel provides confinement while the concrete effectively bears the compression load. Steel fibres further enhance this performance, particularly at higher replacement percentages.
- Column failure mechanisms include shear failure in the inner core concrete with larger steel fibre particle concentrations and bending and bulging in the steel sections.
- Steel fibre content slightly raises the distance between the yield point and ultimate point, but concrete strength has a greater impact on ductility.

FUNDING INFORMATION

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

ETHICS STATEMENT

This study did not involve human or animal subjects and, therefore, did not require ethical approval.

STATEMENT OF CONFLICT OF INTERESTS

The authors declare no conflicts of interest related to this study.

REFERENCES

[1] Kingsley U. Ukanwa, Charles G. Clifton, James B.P. Lim, Stephen Hicks and Umesh K. Sharma, “Numerical analysis of plain and steel fiber reinforced concrete filled steel tubular slender column,” *Advanced Steel Construction*, vol. 14, no. 2, pp. 308-323, 2018. doi: 10.18057/IJASC.2018.14.2.10.

[2] X. Hu *et al.*, “Effect of steel fibres and expansive agents on compressive behaviour of circular CFST columns,” *Case Studies in Construction Materials*, vol. 20, p. e02789, Dec. 2023, doi: 10.1016/j.cscm.2023.e02789.

[3] L. Wang *et al.*, “The influence of fiber type and length on the cracking resistance, durability and pore structure of face slab concrete,” *Construction and Building Materials*, vol. 282, p. 122706, Feb. 2021, doi: 10.1016/j.conbuildmat.2021.122706.

[4] F. A. Abdelfattah, H. Eltobgy, E. Darwish, and H. F. Ali, “Numerical study of axially loaded perforated cold-formed steel RHS stub columns,” *Deleted Journal*, vol. 53, no. 3, pp. 174–184, Jul. 2024, doi: 10.21608/erjsh.2024.280818.1288.

[5] Hanan Eltobgy, Salah Abdallah, Ibrahim Shaaban, “Behavior and Design of Steel Box Columns In-Filled with Plain and Steel Fiber Reinforced Concrete under Centric and Eccentric Loads,” *WULFENIA Journal*, vol. 20, no. 5, 2013.

[6] F. Aslani, B. Uy, Z. Tao, and F. Mashiri, “Behaviour and design of composite columns incorporating compact high-strength steel plates,” *Journal of Constructional Steel Research*, vol. 107, pp. 94–110, Feb. 2015, doi: 10.1016/j.jcsr.2015.01.005.

[7] Z. Yang, G. Li, Y. Lang, and Z. Qiu, “Behavior of High Strength Concrete Filled Square Steel Tube Stub Columns with Inner CFRP Tube Under Biaxial Eccentric Compression,” *Computer Modeling in Engineering & Sciences*, vol. 127, no. 1, pp. 273–290, Jan. 2021, doi: 10.32604/cmes.2021.014606.

[8] Feng Yu, Yue Cao, Yuan Fang, Yuan-Di Qian, Chi Yao and Yin Qin, “A model for predicting moment-curvature behavior of self-stressing SSACFST columns under low cyclic loading,” *Advanced Steel Construction*, vol. 18, no. 4, pp. 736-744, 2022. doi: 10.18057/IJASC.2022.18.4.1.

[9] Q.-H. Wang, J.-F. Liang, C.-F. He, and W. Li, “Axial compressive behavior of steel Fiber-Reinforced recycled coarse aggregate Concrete-Filled short circular steel columns,” *Advances in Materials Science and Engineering*, vol. 2021, no. 1, Jan. 2021, doi: 10.1155/2021/5516893.

[10] W. Feng *et al.*, “Experimental study on the effect of strain rates on the dynamic flexural properties of rubber concrete,” *Construction and Building Materials*, vol. 224, pp. 408–419, Jul. 2019, doi: 10.1016/j.conbuildmat.2019.07.084.

[11] R. Kurda, J. De Brito, and J. D. Silvestre, “Water absorption and electrical resistivity of concrete with recycled concrete aggregates and fly ash,” *Cement and Concrete Composites*, vol. 95, pp. 169–182, Oct. 2018, doi: 10.1016/j.cemconcomp.2018.10.004.

[12] G. Ren, H. Shang, P. Zhang, and T. Zhao, “Bond behaviour of reinforced recycled concrete after rapid freezing-thawing cycles,” *Cold Regions Science and Technology*, vol. 157, pp. 133–138, Oct. 2018, doi: 10.1016/j.coldregions.2018.10.005.

[13] J.-F. Liang, Z.-P. Yang, P.-H. Yi, and J.-B. Wang, “Stress-strain relationship for recycled aggregate concrete after exposure to elevated temperatures,” *Computers and Concrete, an International Journal*, vol. 19, no. 6, p. 609, Jun. 2017, doi: 10.12989/cac.2017.19.6.609.

[14] S. Sadati and K. H. Khayat, “Restrained shrinkage cracking of recycled aggregate concrete,” *Materials and Structures*, vol. 50, no. 4, Jul. 2017, doi: 10.1617/s11527-017-1074-y.