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Behaviour of Steel Concrete Composite Infilled Columns Using Light Weight Aggregates and Steel Fibers

Vasanthasurya S [a], Sanjana R [a], Karthikeyan G [b]

Postgraduate Student, Department of Structural Engineering, Kumaraguru College of Technology, Coimbatore, India [a]
Assistant Professor, Department of Structural Engineering, Kumaraguru College of Technology, Coimbatore, India [b]

ABSTRACT

Steel-concrete composite structures have become increasingly popular in modern construction due to their superior mechanical properties, enhanced fire resistance, and cost- effectiveness. This work provides a comprehensive overview of the recent advancements in the field of Steel-concrete composite construction technology, covering both theoretical and experimental aspects. Steel-concrete composite structures combine the strengths of steel and concrete to create a synergistic system that outperforms either material alone. The behaviour of in filled steel-concrete composites, focusing on the incorporation of both lightweight aggregates as 5% replacement and the introduction of one percent of steel fiber.

The lightweight aggregates is employed to achieve a significant reduction in the self-weight of the composite structure and also minimizes the structural load on the foundation and supporting elements. The lightweight aggregates significantly reduce the self-weight of the structure, while the steel fibers augment the composite's mechanical properties, making it a viable option for construction in various application. This paper investigate the dynamic behaviour of steel-concrete composite infilled columns, exploring the synergistic effects of incorporating lightweight aggregates and steel fibers and their structural performance, durability, and resilience of these composite columns, aiming to optimize their design for enhanced load-carrying capacity and seismic resistance. The results demonstrated that the infilled column experienced failure due to concrete crushing and local buckling of flanges through axial loading. this paper sheds light on the intricate interplay between lightweight aggregates and steel fibers in influencing the mechanical properties of composite columns.

Keywords: steel-concrete composite, infilled columns, lightweight aggregates, steel fibers, structural performance, seismic resistance.

1. Introduction

In order to produce concrete, a heterogeneous material, water, cement, sand and aggregates are blend together. Sand acts as a filler between the aggregates, while cement serves as the binding agent. The primary component in concrete is aggregates, making up 70-80% of its total volume and providing structural strength. There's a growing demand for concrete in construction, driving the search for alternative materials to replace traditional sand and aggregates. Concrete, a widely employed construction material, comprises cement, water and aggregates, renowned for its versatility, robustness and endurance. Throughout centuries, concrete has stood as a cornerstone in erecting buildings, bridges, roads and diverse infrastructure projects. Its adaptability in taking on various forms and sizes makes it well-suited for a wide array of architectural concepts. Its formidable compressive strength guarantees structural stability, while its resistance to fire, water and pests establishes it as a dependable choice for enduring construction. Nonetheless, concrete's production exacts an environmental toll through carbon emissions, spurring ongoing endeavors to cultivate more eco-friendly concrete variants. Despite these challenges, concrete remains an indispensable and foundational element in contemporary construction practices.

Concrete proffers an array of advantages in the construction realm. Its exceptional robustness and longevity render it apt for an extensive spectrum of applications, ensuring enduring structures capable of withstanding substantial loads and adverse weather conditions. Concrete's adaptability permits architects and engineers to breathe life into imaginative designs, bestowing the construction industry with boundless creative possibilities. The cost effectiveness over its lifecycle, stemming from minimal maintenance demands, coupled with its superior fire resistance, bolsters safety protocols. Furthermore, concrete's commitment to sustainability, encompassing the use of recycled materials and the reduction of carbon emissions, underscores its ecofriendliness. These merits, complemented by its sound insulation attributes and resistance to pests, solidify concrete as the favored choice in the construction arena. However, it is vital to acknowledge that concrete's weight can restrict its utility in certain contexts, such as high-rise structures, where meticulous weight management is imperative.

Expanded clay aggregates, often referred to as expanded clay pellets or balls, are highly versatile materials celebrated for their unique properties. These aggregates are created by subjecting natural clay to high temperatures in a rotary kiln, causing it to expand and adopt a lightweight, spherical shape. Their most prominent attribute is their exceptional lightness, making them an ideal choice in construction for reducing overall structural loads while maintaining strength. Moreover, expanded clay aggregates excel in providing insulation, enhancing energy efficiency and sound attenuation in construction projects.

Beyond construction, they play a crucial role in horticulture, serving as a lightweight and moisture-regulating growth medium in hydroponic and aquaponic systems. Their porous structure facilitates effective moisture control and aeration, making them invaluable in both construction and agricultural contexts. Their non-reactive and non-toxic nature ensures safety and reliability. Whether incorporated into lightweight concrete compositions or utilized as nurturing substrates for thriving vegetation, expanded clay aggregates underscore their versatility and indispensability across diverse industries.

Contrarily, lightweight concrete is a variation of conventional concrete that has a considerably lower density. Lightweight concrete has a lower density that ranges from 300 kg/m3 to 1850 kg/m3, as opposed to conventional concrete, which typically has a density between 2200 kg/m3 and 2600 kg/m3. Due to the difference in densities, the material is lighter, which makes it a desirable construction material with certain benefits.

Steel-concrete composite construction is an innovative structural engineering approach that combines two construction materials, steel and concrete, to create composite structural elements with enhanced performance characteristics. This method involves using steel beams or sections in conjunction with concrete slabs or shear connectors. Steel provides exceptional tensile strength, making it ideal for resisting horizontal forces like wind and seismic loads, while concrete excels in compressive strength, complementing steel's tensile capacity. This combination efficiently distributes loads, optimizing the use of both materials, resulting in highly durable and load-bearing structures. Steel-concrete composite construction is applied in various sectors, including buildings, bridges, industrial structures, infrastructure, residential construction and retrofitting projects, contributing to efficient and resilient construction practices. The steel-concrete composite material is approximately 30% lighter than reinforced concrete and only slightly heavier than structural steel, with a marginal increase of 2% in weight. This substantial reduction in weight compared to reinforced concrete, coupled with the reduction in the need for extensive false works during construction, plays a significant role in expediting construction schedules. The combination of concrete's strength in compression and steel's strength in tension yields excellent results, enhancing the overall structural performance of composite units. In terms of cost-effectiveness, the steel concrete composite materials can save up to 10% when compared to conventional reinforced concrete and 7% when compared to structural steel. The encasement steel with concrete makes composite structures stronger and adds important protection to the entire building.

2. EXPERIMENTAL INVESTIGATION

2.1 Details of specimens

A Total of three lightweight aggregate infilled columns were fabricated tested. The length of the specimens was 1.1m, and the detailed cross-sectional dimensions were provided in Table1.

Table 1: Specimens' Details and labeling

Cross-Section Dimension (mm)	Steel Thickness (mm)	Length (m)	Concrete Infill	Column's Label
150x200	3 mm	1.2m	5% replacement of LECA with conventional concrete	C1
150x200	3 mm	1.2m	5% replacement of LECA with conventional concrete	C2
150x200	3 mm	1.2m	5% replacement of LECA with conventional concrete	C3

2.2 Materials properties

Cement

In accordance with IS 8112:1989, Ordinary Portland Cement (OPC) of Grade 43 with a specific gravity of 3.15 was utilized in this research project.

Water

Water plays a crucial role in concrete, being both essential and cost-effective. In our experiments and curing, we employed readily available tap water, which possesses a specific gravity close to 1

Fine Aggregate

Following IS 383:1970, this study uses M-Sand (manufacturing sand) passing through a 2.5 mm sieve as fine aggregate. The fine aggregate has a specific gravity of 2.62.

Coarse Aggregate

As per IS 383: 1970, the aggregate of nominal size of 20mm is used. The values of specific gravity is 2.67. Water absorption value is 1.1%.

Light Weight Expanded clay Aggregate

According to IS 9142:1979, this study employs spherical-shaped lightweight expanded clay aggregate with a size range of 8–20 mm. This –20% of its size.aggregate has a specific gravity of 1.82 and exhibits a water absorption value of 18

Figure 2.1 Expanded clay aggregate

Table 2. Coarse Aggregates Properties

Property	**Normal Weight Aggregates**	**Lightweight Aggregates**
Water Absorption %	1.23	11
Bulk Density (Unit Weight kg/m3)	1669	636

Steel fibers

Hooked end typed steel fiber of diameter 0.75 mm and length 60mm is used in this research. It has a tensile strength of 1250 MPa.

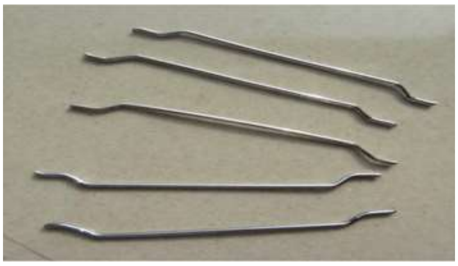

Figure 2.2: Steel fiber

Steel hollow section

As per IS 4923: 1997, Steel hollow section of size 150 mm X 200 mm and length 1200 mm is used in this study. The thickness of the section is 3mm.

Figure 2..3 Steel hollow section

Super plasticizer

The experiment utilizes polycarboxylate ether, a superplasticizer or water reducer, due to its significant water reduction capabilities. This superplasticizer has a measured specific gravity of 1.18 and a water reduction rate of 25%

Mix Design

To determine the mix percentage for M30 grade, the mix design follows the guidelines outlined in IS 10262 – 2019. Consequently, the obtained mix proportion is 1:2:2.7.

Table 3. Mix Properties

Mix	**Coarse Aggregates (kg/m3)**	**Fine Aggregates (kg/m3)**	**Cement (kg/m3)**	**Water (kg/m3)**	**w/c Ratio**	**5% of LECA**
Conventional	1068	791	394	157.6	0.45	_
Leight weight	1014.6	791	394	157.6	0.45	9.489

3 Experimental Test Setup

Axial Loading Test

Axial compressive behaviour testing for steel-concrete composite columns involves applying axial loads to assess their capacity to resist compression. This helps evaluate structural performance, load-carrying capacity, and the interaction between steel and concrete components in the column. The axial load-carrying capacity of a column, you can use Euler's formula for columns. It's important to note that this formula assumes certain conditions and may not cover all real-world scenarios.

Euler's formula for column buckling is given by

P_{cr} = 2.E.I / (K.L)2

Where:

P_{cr} is the critical buckling load.

E is the modulus of elasticity of the material.

I is the moment of inertia of the column's cross-sectional shape.

K is the effective length factor (depends on end conditions, such as fixed or pinned).

L is the effective length of the column.

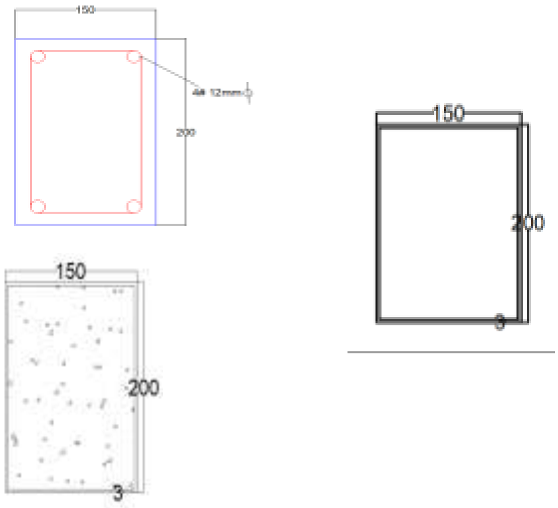

Figure 3.1 Profile of Columns

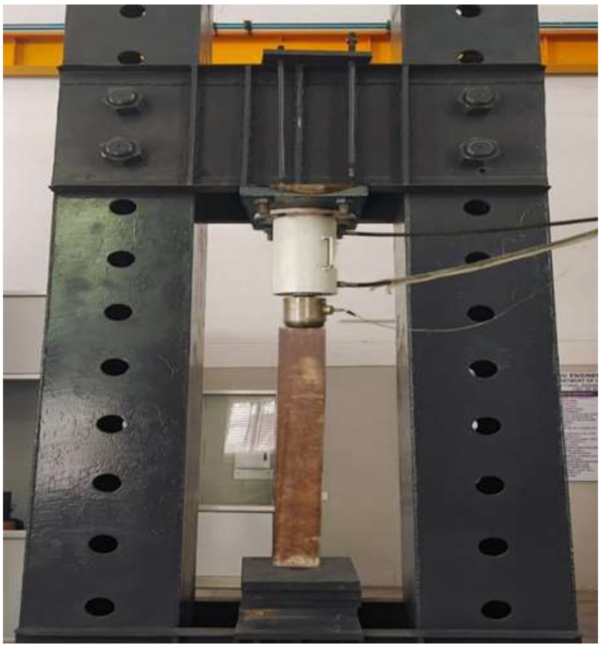

Figure 3.2 Axial Loading test Setup

The tests were conducted in accordance with IS 2911-1-4:(2010).

Loading frame was used to test the column. A graph was created to display Axial loading values shown in figure 5.6. This crucial parameter provides an essential benchmark for understanding the structural limits and ensuring the beam's integrity under real-world conditions.

4. RESULTS AND DISCUSSION:

Table 6.1 Axial Loading Test Result

COLUNM TYPE	**ULTIMATE LOAD**	**ULTIMATE DEFLECTION**
RCC	181.2 KN	6.1mm
Steel Hollow Section	173.41 KN	8.8 mm
Hollow Composite column	323 KN	13.2 mm

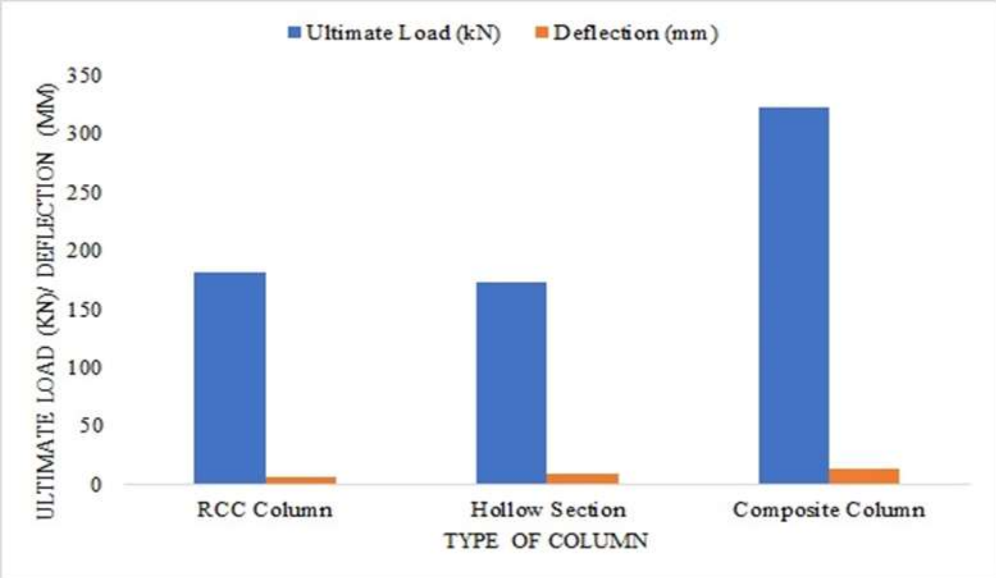

Figure 4.1 Ultimate Load and Deflection of columns

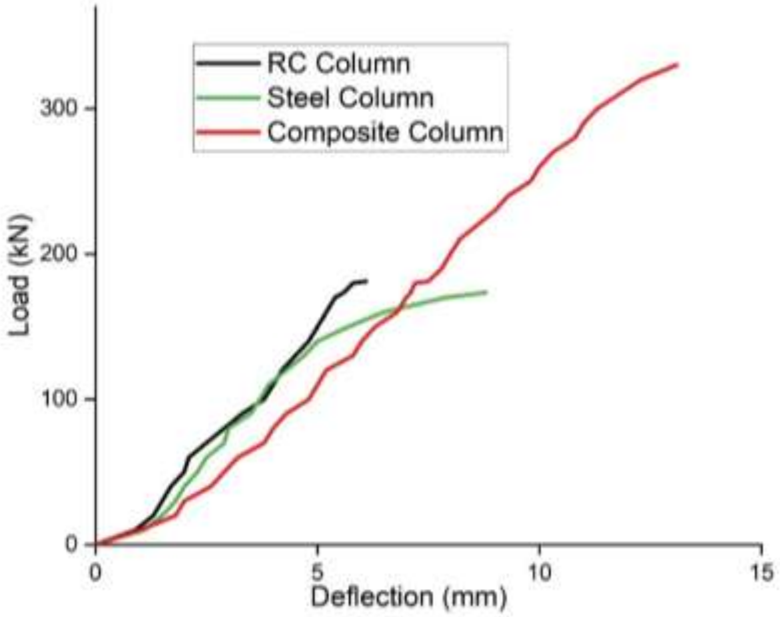

Figure 4.2 Ultimate Load and Deflection Curve

The ultimate load was 323 KN. The load-deflection behaviour of the tested steel-concrete composite infilled column with a 5% lightweight expanded clay aggregate (LECA) content reveals significant insights into its structural performance. The experimentation conducted in a loading frame showcased the structural response of the composite under varying loads. The ultimate load capacity, determined to be 323 kN, signifies the maximum load the column can endure before failure.

Based on the provided table values for ultimate load and ultimate deflection of different column types (RCC, Hollow Section, and Hollow Section with Composite column)

For RCC column Ultimate Load: 181.2 KN and Ultimate Deflection: 6.1 mm RCC columns are traditional and commonly used in construction due to their cost-effectiveness and familiarity in design and construction practices. However, they may have limitations in terms of load-bearing capacity and flexibility compared to newer alternatives.

Hollow Section: Ultimate Load: 173.41 KN and Ultimate Deflection: 8.8 mm Hollow section columns are often preferred for their lighter weight and ease of construction. However, their load-bearing capacity may be slightly compromised compared to solid RCC columns. Hollow Composite Column: Ultimate Load: 323 KN and Ultimate Deflection: 13.2 mm

Composite columns typically consist of steel or other high-strength materials encased within concrete, offering enhanced load-bearing capacity and structural performance compared to conventional RCC or hollow section columns alone.

The significant increase in load capacity and flexibility makes composite columns attractive for applications where higher strength and resilience against deformation are required, albeit potentially at a higher cost compared to traditional column types.

Overall, the choice of column type depends on various factors such as structural requirements, budget constraints, and project specifications. While RCC columns are economical and widely used, hollow section columns offer advantages in terms of weight and construction ease. However, for applications where higher load-bearing capacity and flexibility are paramount, composite columns emerge as a superior option despite their potentially higher cost.

5. Conclusion

The study is to evaluate both the fresh and hardened properties of concrete when incorporating Steel fiber and Lightweight Expanded Clay Aggregates, along with a cement paste coating, as a partial replacement for coarse aggregates. This experiment helped us understand how adding steel fiber and replacing Light weight Expanded Clay Aggregates impacts on fresh concrete and hardened concrete properties and strength. Compressive and split tensile strengths increased at 5% LECA replacement gives high strength integrity and the self-weight of the composite has been reduced. Based on the results, 5% LECA replacement as coarse aggregates is considered the better option. From the outcome, columns are casted and their behaviour under axial compression behaviour will be studied.

Findings revealed distinct load-bearing capacities among different column types. For steel hollow composite columns sections displayed a remarkable increase in strength, reaching a peak load capacity of 323 KN, which is 56% more compare to RCC composite column.

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