CFST Compression members with steel slag as a partial replacement for fine aggregate

Vijayakumar Arumugam¹, Nithya Muthukumaran², Prabakaran Ellappan³

¹Professor, Department of Civil Engineering, GMR Institute of Technology, Rajam, Andhra Pradesh
²Associate Professor, Department of Civil Engineering, CMR Institute of Technology, Medchal (M), Hyderabad
³Assistant Professor, Department of Civil Engineering, Dr.N.G.P. Institute of Technology, Coimbatore

E-mail: vijayakumargmrit@gmail.com

Abstract. Global warming and environmental destruction have become major issues in the last few decades. Use of more and more economical friendly materials in construction is important. Presently in India, steel slag production is about 12 million tonnes per annum, due to limited modes of practices of utilization, steel slags are dumped in yards of each production and engage large area. To overcome these problems steel slag can be used in construction. This paper deals with the study of axial compressive behaviour of Composite column with partial replacement of fine aggregate by steel slag in concrete-filled steel tubular column with different cross-sections. Partial replacement of fine aggregate in Concrete filled steel tubular column will reduce the damage to the ecological balance due to excessive sand lifting from river beds, affecting the ground level. Tests are carried out on the specimens with varying cross-sections and hollow tubular members under axial compression.

1. Introduction

Concrete Filled Steel Tube (CFST) columns find its application in seismic resistance buildings, bridges and subways as structural members such as columns, piers, ribs, deck, abutment, pylons etc. The advantages of high compressive strength, stiffness and ductility of steel tube makes it suitable for seismic resistance members [1]. In addition to these, the steel tube acts as a permanent formwork and external reinforcement for the infilled concrete which reduces material cost and time of construction to a greater extent; concrete prevents and supports the steel tube from local buckling [2]. This has attracted many of the researchers around the world to conduct research on different cross sectional CFST such as circular, square and rectangular. In the recent past, with the development of sustainable concrete technology, new innovative materials were introduced in CFST columns members [3]. In order to introduce sustainability in CFST columns, industrial waste such as waste glass, rubber, foundry sand, fly ash, steel slag can be used for partial replacement of cement, sand or coarse aggregate [4]. Due to rapid urbanization, the dependence on construction industry is increasing rapidly which in turn has increased the demand for river sand.

The steel manufacturing industries produce steel slag as one of the by-products and it is being dumped as landfill which may cause serious environmental challenges. One of the best ways to utilize
the steel slag is by covering them inside the concrete which makes it inert and also provides a sustainable solution for both waste disposal and also reduces the natural river consumption [5]. The type of steel slag produced from the steel industry depends on the method of ore which is used for steel extraction process. The steel slag can be grouped into three types namely, Basic Oxygen Furnace BOF slag, Electric Arc Furnace EAF slag, Ladle Furnace LF slag. The steel slag has low cementitious property and requires activation [6]. However, it can be better utilised as replacements for fine aggregate and coarse aggregate. The following section addresses some of the earlier researches being conducted on steel slag as partial replacement for cement and on CFST column.

Subathra Devi et al.[7], aimed to experiment by partially replacing both coarse aggregate and fine aggregate with steel slag with different ratios such as 10, 20, 30, 40 and 50%, to study the strength property and durability property of concrete. The experimental program involves the prediction of fresh and hardened concrete properties along durability properties such as Rapid Chloride Penetration Test RCPT and acid resistance. The workability test performed using slump cone test reveal that increase in steel slag percentage drastically reduces the slump value and results in a stiff mix. The hardened properties of steel slag concrete reveal that optimum replacement percentage as 40% for fine aggregate and 30% for coarse aggregate. This optimum percentage of replacement was also supported by acid test and RCPT.

Krishna Prasanna, et al. [8], experimented with steel slag as sand replacement material in high strength concrete. The compressive strength of high-performance concrete with 25% of steel slag as replacement for sand exhibits maximum compressive strength and beyond which there is a decline in compressive strength value. However, there is an increase in split tensile strength and flexural strength values for all percentage replacement of steel slag. The properties such as size, shape and texture of slag aggregate provides good adhesion with cement particles.

Shiming Chen et al. [9], conducted experimental investigation to study the structural performance of high tensile steel tubes infilled with ultra-high-strength concrete. Further they extended their study towards identification of mechanical behaviour difference between ultra-high strength and normal concrete filled steel tubes. The analysis of compression characteristics of the specimens includes mode of failure, load versus deflection, axial strength and developed strain. The experimental results exhibit enhanced effect but the performance was not as significant as that of normal concrete. Core strength and ductility of ultra-high strength concrete filled square steel tube was better when compared to circular steel tube. The authors have developed a simplified model for ultimate strength prediction through regression analysis based on the experimental database. It was concluded that the predicted compressive strength values of circular and square cross-section from regression model agreed with the experimental results.

Ming-Xiang Xiong, et al. [10], carried out experimental program on high tensile steel (HTS) tubes infilled with ultra-high-strength concrete (UHSC). The tubular members were subjected to compressive loads with and without eccentricity to examine the buckling resistances and axial moment reaction. In addition, the experimental results were validated using analytical results of support stiffness. In total, 14 members subjected to experimental study in this project have shown ductile behaviour with a smooth peak load curve. Eurocode 4 design method adopted was similar with Finite Element Analysis results. The authors have concluded that more tests need to be conducted to ascertain reliability.

Lai, M.H, Ho, J.C.M [11], investigated the importance of compressive strength of concrete, yield strength of steel, steel ratio and confinement on behaviour of concrete filled steel columns by conducting parametric study. The parametric study utilised the theoretical model developed during their earlier studies, involving the factors such as hoop strain equation, confined concrete and 3D steel model. The external confinement addition is more effective instead of wall thickness increase to achieve good strength and ductility. The results of this study produced two different levels of critical steel ratio and ductility for varying steel yield strength and concrete compressive strength and proposed a new design equation for axial strength of prediction.

The main aim of this paper is to check the suitability of steel slag as partial replacement for fine aggregate in CFST columns with different cross section being subjected to axial compression.
2. Experimental Program

2.1. Materials used

Ordinary Portland Cement of 53 grade was used as per IS 12269-2013 and its quality is verified as per Indian Standard IS 4031 - 1996 specification. The basic properties of cement were checked based on the guidelines in the codal provisions and listed below in Table 1.

| Properties          | Value |
|---------------------|-------|
| Fineness            | 5%    |
| Consistency         | 28%   |
| Initial setting time| 35min |
| Specific gravity    | 3.15  |

Nearby local river sand was used as fine aggregate and 20 mm sized aggregate was used as coarse aggregate. Their properties were verified as per Indian Standards and listed below in Table 2.

| Properties           | FA       | CA       |
|----------------------|----------|----------|
| Specific gravity     | 2.62     | 2.67     |
| Fineness modulus     | 3.25     | 6.89     |
| Loose Bulk Density   | 1420     | 1560     |
| Rodded Bulk Density  | 1580     | 1670     |

2.2. Steel slag

The steel manufacturing plant produces a huge quantity of steel slag as a by-product, which is being used in this project, was crushed into pieces as per the requirement to replace conventional fine aggregate. Various properties of steel slag are given in Table 3.

| Properties      | Value |
|-----------------|-------|
| Voids in sand   | 56%   |
| Specific gravity| 3.0   |
| Water absorption| 1.32% |

2.3 Mix design

Mix design for good degree quality control and mild exposure conditions was done as per IS Bureau of Indian standards IS 10262 – 2019, using the laboratory test values such as specific gravity, water absorption and free surface moisture. The mix proportion was arrived to be 1:1.15:2.24 with a water cement ratio of 0.45.

2.4 Specimen details

The size and quantity of specimens for finding the mechanical properties of concrete is given in Table 4.

| Specimen details | Value |
|------------------|-------|
3. Results and Discussion

3.1. Mechanical Properties

3.1.1. Compressive strength

For nominal and different mix proportions the standard specimen of size 150*150*150 mm has been cast and cured by direct curing method, the specimen is been tested for 7 and 28 days. The inclusion of 30% steel slag for fine aggregate attains higher strength than to nominal concrete. The strength variation for different mix ratios using steel slag is charted in Figure 1.

![Compressive Strength (MPa)](image)

**Figure 1.** Compressive strength (MPa)

3.1.2. Split tensile strength

The determination of split tensile strength using the standard specimen of size 150 mm diameter and 300 mm height has been cast and cured by direct curing method, the specimen is been tested for 7 and 28 days. The inclusion of 30% steel slag for fine aggregate attains higher strength than to nominal concrete. The strength variation for different mix ratios using steel slag is charted in Figure 2.

3.2. Test setup and instrumentation
In total, 8 circular column specimens were tested under for axial compressive load. The test columns were placed in servo-controlled testing machine with a capacity to apply 3000kN and the direct axial load was applied over the specimens. The actuator was driven at a constant speed of 0.5mm/min by controlling the displacement. The specimen axial deformation was measured using displacement transducers placed at three locations vertically. The entire experimental set-up was connected to data acquisition system which records the data synchronously from the strain gauges and LVDT throughout the load increment steps. A seating load of not more than 100 kN was applied to check the consistency of strain gauge value and to find centre line of the applied load. If the variation exceeds 10%, again the pre-load was given until it was repositioned and centred. The axial load was applied with an incremental value of 10kN/s until it reaches the ultimate load.

3.3. Failure mode
The axial compressive load applied on the column specimen exhibit different deformation pattern. The experiment conducted on steel slag concrete filled steel tubes shows bulge in the steel tube at the top of the specimen due to the lateral support on the surface contact [12]. Along the height of the specimen, there were several bulges with the increase in load and deformation. The bulging of steel tube occurs from the top and reaches the mid-height till the annular bulge forms at that location. The hollow square column takes the maximum load compared to the other three types of columns [13].

4. Conclusion
In the present study, the structural behaviours of columns with circular and square cross-sections under axial compression were investigated.

- The study has proved that incorporating steel slag improves the strength of concrete in all aspects.
- It is observed that optimum replacement level of fine aggregate with steel slag was arrived to be 30% based on the compressive strength and split tensile strength tests values.
- The study has analysed the failure modes of both square and circular column specimens due to axial compressive load.
- Under comparison, the hollow square column takes more load than other types of columns.

References
[1] Fa-cheng Wang, Lin-hai Han, Wei Li 2018 Thin-Walled Str. 127 pp 756-768.
[2] Fa-xing Ding, Lei Fu, Zhi-wu Yu 2017 Thin-Walled Str. 115 pp 196-204.
[3] Ganesh Prabhu. G, Sundarraja. M.C, Yun Yong Kim 2015 Thin-Walled Str. 87 pp 139-148.
[4] Nithya M, A.K. Priya, Muthukumaran R, Arunvivek G.K., 2017 Indian J. of Engg. and Mat. Sci. 24 (2) pp 162 -166.
[5] Liusheng He, Yangang Zhao, Siqi Lin 2018 J. of Const. Steel Res. 140 pp 74-81.
[6] Ouyang, Y, Kwan. A.K.H. 2018 Engg Str. 156, pp 443-459.
[7] Subathra Devi.V, Gnanavel. B. K 2018 Proc. Engg. 97, pp 95-104.
[8] Krishna Prasanna, Venkata Kiranmayi 2014 Int. J. of Engg. Res. &Tech. 3 (10).
[9] Shiming Chen, Rui Zhang, Liang-Jiu Jia, Jun-Yan Wang, Ping Gu 2018 Thin-Walled Str. 130, pp. 550-563.
[10] Ming-Xiang Xiong, De-Xin Xiong, J.Y. Richard 2017 J. of Const. Steel Res. 138, pp 168-183.
[11] M.H. Lai, J.C.M. Ho 2017 Thin-Walled Str. 119, pp 770-783.
[12] Qing-Xin Ren, Kan Zhou, Chao Hou, Zhong Tao, Lin-Hai Han 2018 Thin-Walled Str. 124, pp 291-302.
[13] Wu Xu, Lin-Hai Han, Wei Li 2016 J. of const. steel res. 123, pp 162-175.