A Review on Developments of Concrete-Filled Steel Tubes in Recent Time

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Abstract

This review explores Concrete Filled Steel Tubular (CFST) structures, examining how they perform and their potential role in future construction projects. CFST combines concrete and steel, offering both strengths and weaknesses. We break down these aspects in simple terms, looking at how CFST behaves in different situations. By pulling insights from various research papers, we aim to provide a clear understanding of CFST technology's trajectory. From its superior strength to potential drawbacks, we delve into how CFST shapes up in diverse scenarios. This examination offers valuable insights into the evolving landscape of CFST and its implications for construction practices in the future. In essence, this review offers a straightforward overview of how ongoing research efforts are shaping our understanding of CFST. It underscores the significance of CFST technology and its potential contributions to the future of construction, all in an easy-to-understand manner.

Keywords: CFST structures, Axial-load, Residual Bond, stainless-steel, compressive strength, bearing capacity.

1. INTRODUCTION

1.1 Concrete

Concrete is a versatile construction material made up of a binder (usually cement), aggregate (like sand or gravel), and water. When these ingredients are mixed, they form a paste that hardens over time, binding the aggregates together into a solid mass. Concrete provides compressive strength whereas it lacks tensile strength. In some of research studies, different types of concrete were used:

1.1.1 Residual Bond Strength between Steel Tube and outside Concrete after Heating by Kai Xiang, Yanchong Pan (Oct 2019) used Concrete made from limestone aggregates

1.1.2 Study on Concrete Filled Steel Circular and Square Tubes by P.B.M.R. Bogahawaththa, K. P. Madhuranga, K. Baskaran, Hidallana-Gamage H. D. (July 2020) Used Fly ash concrete with varying strengths (30 MPa and 40 MPa), and normal concrete.

1.1.3 Axial-load response of CFST stub columns with external stainless steel and recycled aggregate concrete by Zhang W-H., Wang R., Zhao H., Lam Dennis, Chen P. (2022) Used Recycled aggregate concrete (RAC)

These variations in concrete types allow researchers to explore different properties and behaviours of concrete-filled structures in construction.

1.2 Steel

Steel, at its core, is iron combined with a small amount of carbon, typically less than 2%. However, its versatility extends beyond this basic composition. By incorporating additional elements like chromium, manganese, and nickel, various grades of steel alloys with diverse properties can be crafted. The types of steel mentioned in the research summaries are as below:

1.2.1 Residual Bond Strength between Steel Tube and outside Concrete after Heating (Oct 2019) by Kai Xiang and Yanchong Pan the Carbon steel tubes were likely used in this research.

1.2.2 Study on Concrete Filled Steel Circular and Square Tubes (July 2020) by P.B.M.R. Bogahawaththa the Carbon steel tubes were likely used in this research.

1.2.3 Axial-load response of CFST stub columns with external stainless steel and recycled aggregate concrete: Testing, mechanism analysis and design (2022) by Zhang, W-H.; Wang, R.; Zhao, H.; Lam, Dennis; Chen, P. The Stainless-steel tubes were used in this research, particularly in the context of concrete-filled stainless-steel tubes (CFSST).

1.3 Reinforced concrete

Reinforced concrete is a special type of concrete that includes steel bars or mesh within it. This steel reinforcement helps the concrete handle various types of forces, like pulling (tensile), pushing (compressive), and sliding (shear). Plain concrete is not great at resisting pulling and sliding forces, which can come from things like wind, earthquakes, or vibrations. But when you add steel into the mix, the combination becomes much stronger. The steel takes care of the pulling part (Tension), while the concrete handles the pushing (Compression). Together, they make a material that can withstand lots of different stresses without breaking easily. It's like having a team where each member has their own strengths, and together, they can tackle anything that comes their way.

1.4 Concrete-filled steel tubular (CFST)

Concrete-filled steel tubular (CFST) columns, renowned for their composite structure combining an inner steel tube and an outer encased concrete layer, have emerged as a pivotal element in civil engineering due to their exceptional mechanical properties and construction feasibility. The amalgamation of steel and concrete in CFST columns imparts them with advantageous characteristics, including high load-bearing capacity, excellent ductility, superior seismic performance, and ease of construction. This introduction embarks on a comprehensive overview of significant research endeavours that collectively shape our understanding of CFST columns, exploring diverse aspects ranging from fire resistance to axial loading, corrosion resistance, and the integration of alternative materials.

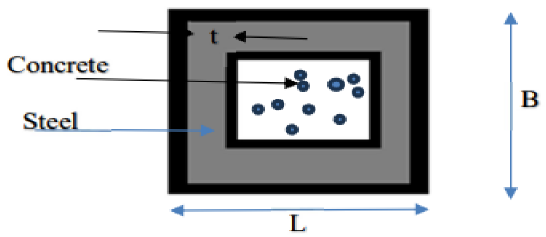

Fig -1: Cross-section of CFST

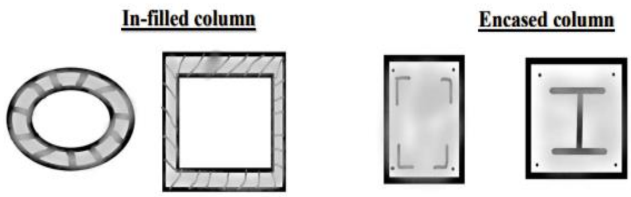

Fig -2: Type of composite column

1.5 Different Studies on CFST:

Kai Xiang and Yanchong Pan's seminal study in collaboration with the Tianjin Fire Research Institute initiated the exploration of post-fire Behaviour in CFST columns [1]. Focusing on the residual bond strength between the steel tube and the outer concrete layer after exposure to elevated temperatures, this research laid the groundwork for comprehending the performance of CFST structures under fire conditions. Subsequent investigations by Zhou K., R.H. Haddad, A. Ergün, Yang H., Yuan. G. delved into the intricacies of post-fire bond strength, extensively examining the interplay between steel bars and concrete or high-strength concrete in varying scenarios. These investigations have explored post-fire bond Behaviour, considering factors such as fire exposure time, cross-section type, concrete strength, and curing conditions. The cumulative findings from these studies contribute significantly to our understanding of CFST columns' Behaviour under fire conditions and provide insights into optimizing their design for enhanced safety.

P.B.M.R. Bogahawaththa's 2020 study further augments our comprehension of CFST, emphasizing the advantages of composite materials in enhancing compressive strength, mitigating local buckling tendencies, and improving fire resistance [2]. Examines the effects of various parameters on compressive behaviour and failure modes of CFSTs, providing valuable data for design considerations.

Zhang's research addresses environmental concerns by reducing stainless steel use and enhancing recycled concrete. Limited work on RAC-FSST columns underscores the need for further investigation [3]. Additionally, different studies by Fa-xing Ding, Xi-Feng Yan, Yong Xu & Lanhui Guo collectively explore axial-loaded behaviour in composite columns. They highlight stainless steel advantages, innovative designs, and contribute insights for structural engineering, emphasizing themes like confinement effects, numerical analysis, and design guidelines [4-6,11].

Analytical studies by Hongyuan Tang. focused on concrete-filled circular stainless-steel tubular (CFCSST) stub columns, elucidating mechanical Behaviours and confinement effects. The study identified a gap in understanding the confinement coefficient of CFST columns, prompting further exploration [7].

Mizan Ahmed 's study Focuses on the use of rectangular CFSST columns, emphasizing their structural performance compared to conventional CFST columns [8]. Meanwhile, Soner Guler. Investigates the use of hybrid fiber-reinforced concrete in CFST columns for improved performance [9].

Qiyun Qiao’s experimental investigation provides experimental data on the axial compressive behaviour of concrete-filled stainless-carbon steel tube columns, offering insights into their mechanical performance [10].

Experimental and numerical investigations of concrete-filled Stainless-Steel tube stub columns under axial partial compression by An He, Ou Zhao [12] provide valuable insights into the axial Behaviour of CFST columns, particularly under partial compression scenarios.

Lin-Hai Han, Chuan-Yang Xu, Zhong Tao's summary of recent research [13] comprehensively reviews the state-of-the-art of concrete-filled Stainless-Steel tubular members and joints, summarizing experimental investigations on the bond Behaviour of CFSST members and joints under various loading conditions.

Guochang Li, Zhichang Zhan, Zhijian Yang, Chen Fang, Yu Yang's study [14] delves into the Behaviour of concrete-filled square steel tubular stub columns stiffened with encased I-section CFRP profiles under biaxial bending, introducing a novel composite member designed to enhance load-bearing capacity and reduce construction costs.

Lieutenant Colonel Muhammad Sanaullah, Jesika Rahman, Ibriju Ibrahim, and Major Md. Soebur Rahman's study [15] focuses on the Behaviour of concrete-filled Stainless-Steel tubular columns under axial load, adding valuable insights into the application of CFSST columns in composite structures.

The series of studies collectively enhance our understanding of Concrete-Filled Steel Tubular (CFST) columns across diverse dimensions. Initial research on post-fire behaviour, spearheaded by Kai Xiang, Yanchong Pan, Zhou K., R.H. Haddad, A. Ergün, and Yang H., establishes a crucial foundation for designing fire-resistant CFST structures. Simultaneously, the work of W.-H. Zhang, P.B.M.R. Bogahawaththa, Xi-Feng Yan, Yong Xu, and Lanhui Guo addresses environmental concerns by delving into strategies to reduce stainless steel consumption and incorporate recycled materials in CFST, aligning with sustainable practices. Investigations into axial-loaded behaviour provide valuable insights into the advantages of stainless steel and innovative design concepts. Hongyuan Tang's analytical studies, Mizan Ahmed's focus on different column shapes, and Qiyun Qiao's experimental data contribute to a deeper understanding of mechanical behaviours and confinement effects.

Moreover, An He and Ou Zhao's exploration of axial partial compression scenarios, as well as Lin-Hai Han, Chuan-Yang Xu, and Zhong Tao's comprehensive review, highlight the importance of considering various loading conditions and provide a state-of-the-art synthesis of recent research. Furthermore, Guochang Li, Zhichang Zhan, Zhijian Yang, Chen Fang, and Yu Yang's study introduces novel composite members, showcasing the potential to enhance load-bearing capacity while reducing construction costs. Finally, Lieutenant Colonel Muhammad Sanaullah, Jesika Rahman, Ibriju Ibrahim, and Major Md. Soebur Rahman's study adds valuable insights into the practical application of CFST columns in composite structures. In aggregate, these research endeavours provide a holistic perspective, contributing significantly to the optimization of CFST designs for enhanced structural performance and diverse engineering applications.

2. LITERATURE REVIEW

The literature review is a pivotal component of this research paper, synthesizing insights from a diverse array of studies that collectively contribute to the understanding and advancement of Concrete-Filled Steel Tube (CFST) structures.

2.1 In 2018, Lin-Hai Han, Chuan-Yang Xu, and Zhong Tao summarized research on the performance of Concrete-Filled Stainless-Steel Tubular (CFSST) columns and joints. Their aim was to highlight enhanced properties of CFSST structures and explore connections with carbon steel beams. They observed improved ductility and fire performance.

2.2 In 2019, Lanhui Guo, Feng Fu, Yong Liu, and Haijia Huang explored the behavior of axially loaded Stainless-Steel tube-confined concrete stub columns and concrete-filled Stainless-Steel stub columns. Their aim was to explore both types' high load-carrying capacity and assess the impact of welding quality on deformation ability. They proposed a formula for calculating load-carrying capacity, emphasizing the significant contribution of welding quality.

2.3 In 2019, An He and Ou Zhao investigated the behavior and load-carrying capacities of circular CFSST stub columns in partial compression. Their aim was to conduct thorough testing and numerical simulation to accurately estimate P/Pu-M/Mu curves for CFSST columns in partial compression. They concluded by providing empirical equations for estimating load-carrying capacities.

2.4 In October 2019, Kai Xiang and Yanchong Pan investigated the residual bond strength between steel tubes and outside concrete after heating. Their study aimed to explore the bond-slip behavior in concrete-encased CFST columns following specified heating. Their conclusion highlighted a decrease in bond failure load post-500ºC high temperature, influenced by temperature and stirrup ratio, while emphasizing the effective fire protection provided by the outer reinforced concrete structure.

2.5 In January 2019, Fa-xing Ding, Yi-xiang Yin, Jianfeng Mao, Li-ping Wang, Yu-jie Yu, and Liang Luo examined the analytical behaviors of concrete-filled circular Stainless-Steel tubular (CFCSST) stub columns under axial loading. Their aim was to investigate CFCSST stub columns under axial loading and propose a validated finite element model. Their findings indicated that composite action surpassed carbon steel counterparts, with the proposed formula accurately predicting bearing capacity, showcasing the superior performance of concrete-filled Stainless-Steel tubes.

2.6 In August 2019, Lieutenant Colonel Muhammad Sanaullah, Jesika Rahman, Ibriju Ibrahim, and Major Md. Soebur Rahman conducted a nonlinear FE analysis of CFSST short columns under axial compressive loads. Their study aimed to assess the behavior of concrete-filled Stainless-Steel tube columns under axial load. They concluded that concrete strength influenced ultimate capacity and noted the conservative nature of existing design codes, particularly regarding strain hardening in cold-formed Stainless-Steel tubes compared to carbon steel.

2.7 In November 2019, Hongyuan Tang, Junlong Chen, Luyao Fan, Xujie Sun, and Chunmei Peng conducted an experimental investigation of FRP-confined concrete-filled Stainless-Steel tube stub columns under axial compression. Their aim was to study failure modes and axial load-shortening curves of FRP-confined CFSSTs. They observed outward buckling and proposed a simplified method for predicting load-carrying capacity, noting that the confinement effect weakened with thicker metal.

2.8 In 2020, Guochang Li, Zhichang Zhan, Zhijian Yang, Chen Fang, and Yu Yang explored the behavior of Concrete-Filled Square Steel Tubular Stub Columns Stiffened with Encased I-Section CFRP Profile Under Biaxial Bending. Their study aimed to investigate the behavior of CFSST stub columns stiffened with encased CFRP profiles under biaxial bending. They observed improved load-bearing capacity and mitigation of local buckling, with empirical equations accurately estimating P/Pu-M/Mu curves.

2.9 In July 2020, P.B.M.R. Bogahawaththa, K. P. Madhuranga, K. Baskaran, and Hidallana-Gamage H. D. conducted a study on Concrete Filled Steel Circular and Square Tubes. Their aim was to analyze the axial compressive capacity of CFST columns based on concrete infill and D/t ratio. They concluded that axial capacity increased with concrete infill but decreased with D/t ratios, validating codes and observing a significant 2.5 times capacity increment experimentally and numerically.

2.10 In 2021, Soner Guler, Demet Yavuz, and Muhammet Aydın investigated hybrid fiber reinforced concrete-filled square stub columns under axial compression. Their aim was to enhance axial load and ductility capacities of hollow columns using concrete filling and fibers. They found that concrete filling improved axial and ductility capacities, with limited effects of steel and synthetic fibers on pre-peak toughness, and observed increased ductility for CFCST and CFSST columns.

2.11 In 2021, Mizan Ahmed, Viet-Linh Tran, Junchang Ci, Xi-Feng Yan, and Fangying Wang conducted computational analysis of axially loaded thin-walled rectangular concrete-filled Stainless-Steel tubular short columns incorporating local buckling effects. Their aim was to assess the axial performance of rectangular CFSST columns and propose effective models and material laws. They concluded that the Bt ratio was crucial for axial performance, with a simple design formula providing more reasonable estimations and discrepancies found in codified design predictions.

2.12 In January 2021, Yong Xu, Hongyuan Tang, Junlong Chen, Yigang Jia, and Ruizhong Liu performed numerical analysis of CFRP-confined concrete-filled Stainless-Steel tubular stub columns under axial compression. Their aim was to analyze the behavior of CFRP-CFSST under axial compression and assess the impact of CFRP layers. They found good agreement between FEA and experimental results, with CFRP layers influencing contact stress and longitudinal stress while noting minimal impact from Stainless-Steel properties.

2.13 In 2022, Zhang W-H., Wang R., Zhao H., Dennis Lam, and Chen P. investigated the axial-load response of CFST stub columns with external Stainless-Steel and recycled aggregate concrete. Their aim was to investigate the axial-load responses of RAC-FSST stub columns and evaluate design code applicability. They observed various failure modes, identified strain-softening and strain-hardening responses, and concluded that design codes for normal CFSTs applied, with concrete strength and steel ratios influencing failure modes.

2.14 In 2021, Xi-Feng Yan, M.F. Hassanein, Fangying Wang, and Meng-Nan He examined the behavior and design of high-strength concrete-filled rectangular ferritic Stainless-Steel tubular short columns subjected to axial compression. Their aim was to examine the axial performance of CFFSST columns and assess the impact of concrete strength and dimensions. They concluded that increased strength and cost savings were achievable with concrete filling, noting that high-strength concrete was economical for thin columns, with concrete strength influencing stiffness, strength, and ductility.

2.15 In 2021, Qiyun Qiao, Jiafeng Li, and Zhaoyuan Yang investigated the axial compressive behavior of concrete-filled stainless-carbon steel tube columns. Their aim was to investigate the axial behavior of CFSCT columns under compressive loading. They found that carbon steel tubes enhanced strength, with higher concrete strength and thicker tubes increasing ultimate strength, and observed that post-peak ductility was influenced by carbon steel tube wall thickness, with FE models confirming good agreement with test results.

This selection of studies delves into various aspects of concrete-filled Stainless-Steel tube columns, covering Behaviour under different loading conditions, design considerations, and the influence of parameters like welding quality, partial compression, and connections to beams.

3. RESEARCH GAP

There are several potential gaps in the existing studies on concrete-filled steel tube (CFST) columns, particularly those incorporating stainless steel. These gaps suggest areas for further exploration:

3.1. While there are studies on the bond strength between steel and concrete at ambient temperature, there is a lack of research on the residual bond strength after exposure to high temperatures. Investigating how heating affects the bond between stainless steel and concrete in CFST columns could provide insights into the behavior of these columns under fire conditions.

3.2. Several studies mention the benefits of composite action between stainless steel and concrete in CFST columns, but there is limited discussion on the confinement coefficient and its influence on column behavior. Further research could explore how different factors, such as steel thickness and concrete strength, affect the confinement provided by the stainless-steel tube.

3.3. Existing studies primarily focus on axial compression behavior of CFST columns, but there is a gap in understanding how these columns perform under partial compression. Investigating the behavior of CFST columns under varying levels of axial load could provide valuable insights for design considerations in real-world applications.

3.4. While stainless steel is commonly used in CFST columns for its corrosion resistance, there is limited exploration of alternative materials or construction techniques that could enhance performance and reduce costs. Investigating materials like aluminum or innovative construction methods could offer new avenues for improving CFST column design and construction.

3.5. Many studies focus on the mechanical behavior of CFST columns, but there is a gap in research on their long-term durability and maintenance requirements, especially in aggressive environments. Investigating the performance of CFST columns over extended periods of time and under various environmental conditions could inform maintenance strategies and improve their lifespan.

Addressing these gaps through further experimental, numerical, and analytical investigations would contribute to a more comprehensive understanding of CFST column behavior and enhance their performance in structural applications.

4. CONCLUSIONS

In summary, this review examines studies on Concrete-Filled Steel Tubular (CFST) structures, revealing their exceptional mechanical properties, including high load-bearing capacity and resilience to fire. Research by Kai Xiang, Yanchong Pan, and others establishes a foundational understanding of CFST columns' behavior in extreme conditions. Studies by Zhang, Ding, Yan, Xu, and Guo address environmental concerns by exploring sustainable practices.

Analytical studies by Hongyuan Tang, Mizan Ahmed, and Qiyun Qiao contribute insights into mechanical behaviors and axial-loaded performance. Additionally, investigations by Lin-Hai Han, Guochang Li, and Lieutenant Colonel Muhammad Sanaullah provide a holistic perspective on CFST members and joints.

Looking ahead, CFST holds promise for future construction, offering enhanced structural performance and sustainable design options. Further research can explore the residual bond strength after exposure to high temperatures the residual bond strength after exposure to high temperatures also innovative applications, such as incorporating advanced materials and exploring new design concepts. Additionally, investigations into real-world applications and long-term durability will contribute to the practical implementation of CFST in diverse construction scenarios. The ongoing exploration of CFST's potential in composite structures, its role in sustainable construction, and its behaviour in dynamic conditions will shape the future of construction practices.

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