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A Review Paper On Experimental And Computational Investigation Of Compressive Behaviour Of Composite Structural Members Using Finite Element Software

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Abstract: Concrete-Filled Steel Tube (CFST) members are widely recognized as an efficient composite structural system due to their high strength, stiffness, and ductility. This paper presents a comprehensive review of the compressive and flexural behaviour of CFST elements incorporating advanced and sustainable materials such as Self-Compacting Concrete (SCC), fly ash, and graphene oxide. The use of SCC enhances workability and ensures uniform filling in confined steel sections without the need for vibration, while fly ash contributes to sustainability by reducing cement consumption and improving durability. Furthermore, the inclusion of graphene oxide as a nano-material significantly enhances the mechanical properties of concrete by refining its microstructure and reducing micro-cracking. The study also highlights the role of finite element analysis using ANSYS in accurately predicting structural behaviour, stress distribution, and failure modes of CFST members. Based on the review of existing literature, it is observed that the integration of nano-modified SCC in CFST systems leads to improved load-carrying capacity and overall performance. The paper identifies key research gaps and emphasizes the need for combined experimental and computational approaches for the optimized design of composite structural elements.

Index Terms - Concrete-Filled Steel Tube (CFST), Self-Compacting Concrete (SCC), Fly Ash, Graphene Oxide, Composite Structures, Finite Element Analysis (ANSYS), Compressive Behaviour, Flexural Behaviour, Sustainable Materials, Structural Performance.

I. Introduction

In modern structural engineering, the demand for high-performance, durable, and sustainable construction materials has led to the development of composite structural systems. Among these, Concrete-Filled Steel Tube (CFST) members have gained significant attention due to their superior structural efficiency and combined advantages of both steel and concrete. In CFST systems, a hollow steel section is filled with concrete, where the steel tube acts as both permanent formwork and external reinforcement, while the concrete core enhances compressive strength and stiffness. This composite interaction results in improved load-carrying capacity, ductility, and resistance to buckling, making CFST members suitable for applications such as columns, bridge piers, and high-rise structures.

The performance of CFST members is further enhanced by the use of Self-Compacting Concrete (SCC), which is specifically designed to flow under its own weight and fill confined spaces without the need for mechanical vibration. The use of SCC ensures proper compaction within steel tubes, especially in congested or inaccessible sections, thereby eliminating voids and improving structural integrity. Additionally, the incorporation of supplementary cementitious materials such as fly ash contributes to sustainability by reducing cement consumption, lowering carbon emissions, and improving durability characteristics of concrete.

In recent years, the use of nano-materials in concrete technology has emerged as a promising approach to enhance material performance at the microstructural level. Graphene oxide, in particular, has shown significant potential due to its high surface area, strength, and compatibility with cementitious materials. Its inclusion in concrete improves bonding between particles, reduces micro-cracks, and enhances overall mechanical properties. The integration of such advanced materials with CFST systems offers a new direction for achieving both high strength and sustainability in structural design.

Alongside experimental investigations, computational analysis using finite element software such as ANSYS has become an essential tool in structural engineering. Finite element analysis (FEA) allows for accurate prediction of stress distribution, deformation behaviour, and failure modes of structural members under different loading conditions. It also provides a cost-effective and efficient alternative to extensive laboratory testing. The combination of experimental and computational approaches enables better understanding and optimization of CFST performance.

This paper presents a comprehensive review of the behaviour of CFST members incorporating SCC, fly ash, and graphene oxide, along with the role of finite element analysis in predicting their structural performance. The study aims to synthesize existing research, identify current trends, and highlight research gaps for future developments in composite structural systems.

2. Literature Review

Concrete-Filled Steel Tube (CFST) members have been extensively studied over the past few decades due to their superior structural performance and efficient composite action. Researchers have focused on understanding their behaviour under axial, flexural, and combined loading conditions using both experimental and computational approaches.

A study by Gupta et al. (2023) investigated the axial behaviour of CFST columns with varying concrete strengths. The results indicated that an increase in concrete strength significantly enhances the load-carrying capacity of the columns. The authors also utilized finite element analysis using ANSYS, which showed close agreement with experimental results, demonstrating the reliability of numerical modelling in predicting structural behaviour.

Khan et al. (2021) examined the performance of fiber-reinforced concrete-filled steel tube columns under axial loading. Their findings highlighted that the inclusion of fibers improves ductility and delays failure. The study also emphasized that advanced materials can significantly influence the post-peak behaviour of CFST members.

Sharma et al. (2020) focused on the behaviour of concrete-filled steel tubes under different loading conditions and analyzed crack propagation using ANSYS. The simulation results closely matched experimental observations, confirming that finite element analysis can effectively capture crack patterns and stress distribution in composite members.

Rao et al. (2019) conducted both theoretical and experimental investigations on CFST columns with different confinement conditions. Their research demonstrated that confinement provided by the steel tube plays a critical role in enhancing compressive strength and delaying local buckling. The use of numerical modelling further supported their experimental findings.

Dutta et al. (2019) studied the flexural behaviour of CFST beams under static and dynamic loading conditions. Their work revealed that CFST beams exhibit improved load-deflection behaviour and higher energy absorption capacity compared to conventional reinforced concrete beams. The study also highlighted the importance of accurate modelling techniques for predicting flexural performance.

Earlier work by Rav et al. (2016) explored the nonlinear response of CFST columns subjected to axial compression. The researchers observed that the composite interaction between steel and concrete significantly improves stiffness and load resistance. Their study emphasized the importance of combining experimental testing with computational tools to achieve reliable results.

In addition to structural performance, recent research has increasingly focused on the use of sustainable and advanced materials in CFST systems. The incorporation of fly ash as a partial replacement for cement has been widely reported to improve workability, reduce heat of hydration, and enhance long-term durability. Similarly, Self-Compacting Concrete (SCC) has gained popularity due to its ability to flow easily and fill confined steel sections without vibration, ensuring better compaction and uniformity.

Furthermore, the application of nano-materials such as graphene oxide has emerged as a promising area of research. Studies have shown that graphene oxide enhances the microstructure of concrete, leading to increased compressive strength, reduced permeability, and improved resistance to cracking. However, the integration of nano-materials in CFST systems is still in its early stages and requires further investigation.

Overall, the reviewed literature indicates that CFST members provide superior structural performance compared to traditional systems. While significant progress has been made in understanding their behaviour, there remains a need for comprehensive studies that combine sustainable materials, nano-modification, and advanced computational analysis to fully exploit the potential of CFST systems.

3. MATERIALS USED IN PREVIOUS STUDIES

The performance of Concrete-Filled Steel Tube (CFST) members is significantly influenced by the type and properties of materials used. Various researchers have explored different materials and modifications to enhance the strength, durability, and sustainability of CFST systems. The commonly used materials in previous studies are discussed below.

3.1 Steel Tubes

Steel tubes form the outer shell of CFST members and play a crucial role in providing confinement to the concrete core. Most studies have used circular, square, or rectangular hollow steel sections depending on structural requirements. The steel tube not only acts as permanent formwork but also contributes to axial strength and resistance against buckling. Researchers have reported that the confinement effect of steel delays the onset of cracking and improves ductility. The thickness and yield strength of steel significantly influence the overall performance of CFST members.

3.2 Concrete

Concrete acts as the core material in CFST systems and primarily resists compressive loads. Different grades of concrete, ranging from normal strength to high-strength concrete, have been used in various studies. Higher concrete strength generally leads to increased load-carrying capacity; however, it may also result in brittle behaviour if not properly confined. The interaction between steel and concrete ensures improved stress distribution and composite action.

3.3 Self-Compacting Concrete (SCC)

Self-Compacting Concrete (SCC) has been widely adopted in CFST applications due to its excellent flowability and self-leveling properties. SCC can fill confined steel sections without the need for vibration, ensuring uniform compaction and eliminating voids. Previous studies have shown that SCC improves the bond between steel and concrete, resulting in enhanced structural performance. It is particularly beneficial in situations where conventional compaction methods are not feasible.

3.4 Fly Ash

Fly ash is commonly used as a partial replacement for cement in concrete to improve sustainability and workability. Several researchers have incorporated fly ash in CFST systems to reduce the environmental impact of cement production. The use of fly ash enhances the durability of concrete, reduces heat of hydration, and improves long-term strength. It also contributes to better workability, which is essential for SCC applications.

3.5 Nano-Materials (Graphene Oxide)

Recent studies have explored the use of nano-materials to improve the microstructural properties of concrete. Graphene oxide is one of the most promising nano-materials due to its high surface area, strength, and chemical stability. Its inclusion in concrete has been shown to enhance compressive strength, reduce micro-cracking, and improve durability. However, research on the application of graphene oxide in CFST systems is still limited, indicating the need for further investigation.

3.6 Admixtures

Chemical admixtures, particularly superplasticizers, are widely used in SCC to achieve the required flowability without increasing water content. These admixtures help in reducing the water-cement ratio while maintaining workability, thereby improving strength and durability. Many studies have highlighted the importance of admixture dosage in achieving optimal performance of SCC in CFST applications.

Overall, previous research indicates that the combined use of advanced materials such as SCC, fly ash, and nano-materials significantly enhances the structural performance and sustainability of CFST members. However, the integration of these materials in a single system and their combined effects require further detailed investigation.

4. COMPARISON BETWEEN CFST AND CONVENTIONAL STRUCTURAL MEMBERS

Parameter	**CFST (Concrete-Filled Steel Tube)**	**Conventional RCC Members**
Structural System	Composite (Steel + Concrete)	Reinforced Concrete
Load Carrying Capacity	Higher due to confinement effect	Moderate
Ductility	High (gradual failure)	Low (brittle failure)
Construction Time	Faster (no formwork required)	Slower (requires formwork)
Compaction	No vibration needed (with SCC)	Requires vibration
Buckling Resistance	High due to steel confinement	Lower
Durability	High	Moderate
Material Efficiency	High (smaller section size)	Lower (larger sections needed)
Cost Efficiency	Economical in long term	Higher maintenance cost
Failure Mode	Gradual and ductile	Sudden and brittle

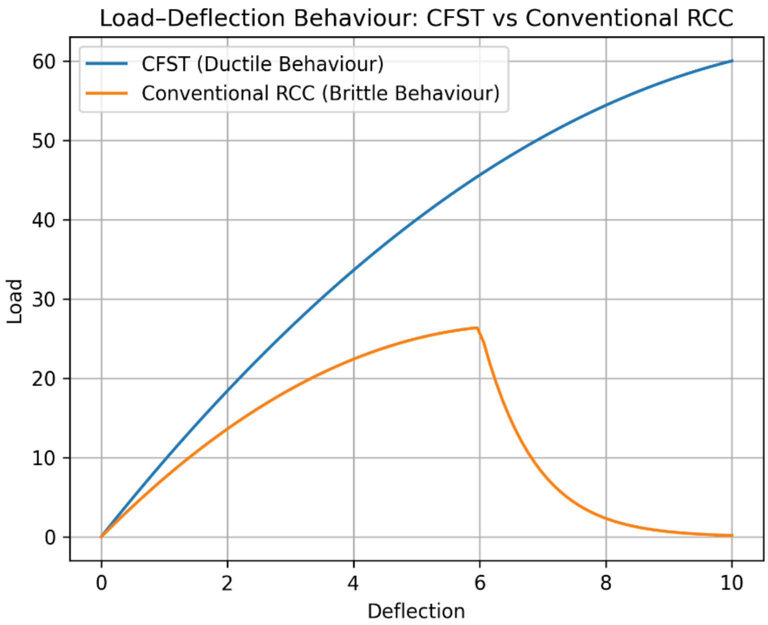

Figure: Load–Deflection Behaviour of CFST and Conventional RCC Members.

CFST members exhibit higher load-carrying capacity and improved ductility compared to conventional RCC members due to the composite action between steel and concrete. The load–deflection curve for CFST shows gradual deformation, indicating ductile behaviour and higher energy absorption capacity. In contrast, conventional RCC members display relatively brittle behaviour with a sudden reduction in load after reaching peak strength. This difference highlights the superior performance of CFST systems in resisting structural loads and delaying failure.

5. ROLE OF FINITE ELEMENT ANALYSIS (ANSYS)

Finite Element Analysis (FEA) has become an essential tool in modern structural engineering for analyzing and predicting the behaviour of complex systems such as Concrete-Filled Steel Tube (CFST) members. With the advancement of computational techniques, software platforms like ANSYS are widely used to simulate the structural response of composite elements under various loading conditions, including axial compression, bending, and combined loads.

ANSYS enables the development of detailed numerical models that accurately represent the geometry, material properties, and boundary conditions of CFST members. By incorporating nonlinear material behaviour for both steel and concrete, FEA can effectively simulate real-life conditions such as yielding of steel, cracking and crushing of concrete, and interaction between the two materials. This allows researchers to study stress distribution, deformation patterns, buckling behaviour, and failure modes with high precision.

Several studies have demonstrated that the results obtained from ANSYS simulations closely match experimental findings, validating the reliability of finite element modelling. This correlation provides confidence in using computational analysis as a predictive tool, reducing the need for extensive laboratory testing, which can be time-consuming and costly. Additionally, FEA allows for parametric studies where different variables such as material properties, cross-sectional dimensions, and loading conditions can be altered to evaluate their effects on structural performance.

Another significant advantage of ANSYS is its ability to visualize internal responses that are difficult to observe experimentally. Contour plots of stress, strain, and deformation help in identifying critical regions within CFST members, such as zones of maximum stress concentration or potential crack initiation. This insight is valuable for optimizing design and improving structural safety.

Furthermore, finite element analysis supports the integration of advanced materials such as Self-Compacting Concrete (SCC), fly ash, and nano-materials like graphene oxide. By modelling these materials with appropriate properties, researchers can predict their influence on overall structural behaviour before practical implementation. Overall, the use of ANSYS in CFST research has significantly enhanced the understanding of composite structural behaviour. It serves as a powerful complement to experimental studies, enabling accurate analysis, design optimization, and development of innovative structural systems.

6 RESEARCH GAPS AND FUTURE SCOPE

Although extensive research has been carried out on Concrete-Filled Steel Tube (CFST) members, several important gaps still exist in the current body of knowledge. Most of the previous studies have primarily focused on conventional concrete and standard material combinations, with limited attention given to the use of advanced and sustainable materials in CFST systems.

One of the major research gaps is the limited investigation on the combined use of Self-Compacting Concrete (SCC) and supplementary cementitious materials such as fly ash within CFST members. While SCC has been widely studied for its flowability and compaction advantages, its interaction with steel confinement in CFST systems, especially with partial cement replacement, requires further detailed analysis. Another significant gap is the insufficient exploration of nano-materials, particularly graphene oxide, in CFST applications. Although graphene oxide has shown promising results in enhancing the mechanical and durability properties of concrete at the microstructural level, very few studies have examined its influence on the overall structural performance of CFST members under axial and flexural loading conditions.

Furthermore, many studies have either focused on experimental investigations or computational simulations independently. There is a lack of integrated research that combines both experimental testing and finite element analysis (FEA) for validation and comprehensive understanding. The correlation between laboratory results and numerical modelling needs to be explored in greater depth to ensure the accuracy and reliability of predictive models.

Additionally, limited research is available on the performance of CFST members using M40 grade Self-Compacting Concrete, particularly under varying loading conditions. Most existing studies focus on either lower or higher strength grades, leaving a gap in understanding the behaviour of medium-strength SCC in composite systems. Moreover, the influence of multiple parameters such as material composition, confinement effects, and loading conditions has not been fully studied in a unified framework. The combined effect of sustainable materials, nano-modification, and structural interaction in CFST members remains an area requiring further investigation. Therefore, there is a clear need for comprehensive studies that integrate sustainable materials, nano-technology, and advanced computational techniques to better understand and optimize the performance of CFST systems. Addressing these gaps will contribute to the development of more efficient, durable, and environmentally friendly structural solutions.

7. CONCLUSION

This paper presented a comprehensive review of the structural behaviour of Concrete-Filled Steel Tube (CFST) members incorporating advanced and sustainable materials such as Self-Compacting Concrete (SCC), fly ash, and graphene oxide. Based on the analysis of existing literature, it is evident that CFST systems offer significant advantages over conventional structural elements, including higher load-carrying capacity, improved ductility, enhanced stiffness, and better resistance to buckling due to the composite action between steel and concrete.

The use of SCC has proven to be highly beneficial in CFST applications, as it ensures complete and uniform filling of confined steel sections without the need for mechanical vibration, thereby improving structural integrity. The incorporation of fly ash contributes to sustainability by reducing cement consumption, lowering environmental impact, and enhancing long-term durability. Furthermore, the inclusion of nano-materials such as graphene oxide has shown promising potential in improving the microstructure of concrete, leading to increased compressive strength and reduced cracking.

The review also highlights the critical role of finite element analysis using ANSYS in accurately predicting the structural behaviour of CFST members. Computational modelling has been found to closely correlate with experimental results, making it a reliable and efficient tool for analysis and design optimization.

Despite significant advancements, several research gaps remain, particularly in the combined use of SCC, fly ash, and graphene oxide within CFST systems, as well as the need for integrated experimental and computational studies. Addressing these gaps can lead to the development of more efficient, durable, and sustainable structural solutions.

In conclusion, CFST systems enhanced with advanced materials and supported by modern computational tools represent a promising direction for future structural engineering applications. Further research in this area will contribute to optimizing design practices and improving the overall performance of composite structural members.

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