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(Review Article)

Progress in Ferrocement-Confinement Techniques for Self-Compacting Concrete: Structural Insights

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Received: 10.05.2026 | Accepted: 15.05.2026 | Published: 20.05.2026

ABSTRACT

This review paper offers a state-of-the-art, and in-depth overview of how SCFC behaves structurally. SCFC combines the high workability of SCC with the tensile properties and crack resistance of ferrocement. The review primarily includes publications between 2020–2025. In addition to these recent studies, it also includes some foundational studies conducted in 2011–2022. Across all studies reviewed (n=28), there was consistency in terms of what is known about the effects of confining ferrocement on SCC. Specifically, the results show that SCC confined with ferrocement can provide higher load-carrying capacities, enhanced ductilities, increased energy absorptions, and improved crack resistances than unconfined SCC. Some examples of more recently developed approaches for enhancing the performance of SCFC include using geopolymers; the use of sustainable SCM's (e.g., FA, GGBFS, SF); and ML-assisted optimization of SCFC mixes. Finally, the Review Paper includes a separate discussion on research gaps which identifies those problems most urgently requiring resolution. These include developing new constitutive models for predicting SCFC behavior under various loading conditions; assessing seismic behavior; evaluating long-term durability; and establishing standardized design procedures.

Keywords: *Self-Compacting Concrete (SCC), Ferrocement, Self-Compacting Ferrocement Concrete (SCFC), Reinforced Cement Concrete (RCC), Plain Cement Concrete (PCC), Supplementary Cementitious Materials (SCMs).*

I. INTRODUCTION

Self-Compacting Ferrocement Concrete (SCFC) is an innovative composite material that combines the flowability of Self-Compacting Concrete (SCC) with the ability of ferrocement to stop cracks and increase its tensile strength and durability. SCC was developed in Japan in the late 1980s to overcome labor shortages and poor quality issues stemming from the consolidation of reinforced structures [1]. The primary advantage of using SCC over traditional concrete lies in its ability to self-consolidate without the use of vibratory equipment. Thus, when placed, SCC will flow into place by gravity alone allowing for placement at site locations where access is limited. Ferrocement, first introduced in the 1940s, is a thin-walled structure consisting of multiple layers of wire mesh separated by small amounts of a cement-based mortar [14]. Each layer of wire mesh is typically spaced ½" apart resulting in a high surface area-to-volume ratio which allows for an even distribution of tension and assists in stopping crack growth [14]. Therefore, the synergy created between the flowing property of SCC and the confinement property of ferrocement is responsible for creating the engineering value of SCFC. SCFC possesses a higher axial load carrying capacity than either SCC or ferrocement individually; also exhibits greater ductility and impact resistance and absorbs more total energy compared to each individual component. Due to these enhanced properties, SCFC could potentially be applied to various construction projects including marine structures, prefabricated housing panels, thin shell roofs, water retention systems, seismic rehabilitation of RC members, etc. Over the past five years (2020–2025), there has been increasing interest in researching SCFC and some of these recent topics of interest include: Sustainable Binder Systems (Geopolymer and Ternary SCM Blend); Non-Metallic Reinforcement Meshes (Glass-Fiber, Vegetable-Fiber, FRP); Machine Learning Assisted Mix Design Optimization; and Evaluating Dynamic/Seismic Performance.

This paper conducts a review of the relevant literature pertaining to SCFC published since 2011. The focus will be on reviewing literature published after 2020. By conducting a comprehensive review of literature pertinent to SCFC; identifying areas of SCFC research where further research is needed; and providing recommendations for future directions of SCFC research, this paper will provide researchers with a complete body of knowledge on SCFC.

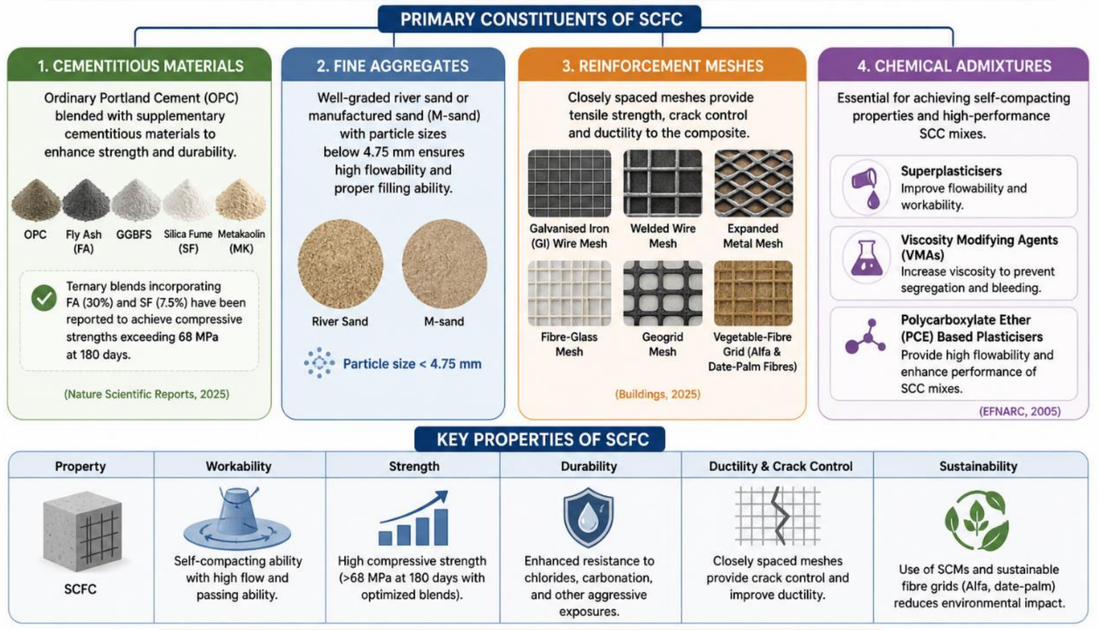


Figure 1. Components and Properties of SCFC.

1.1 Components and Properties of SCFC

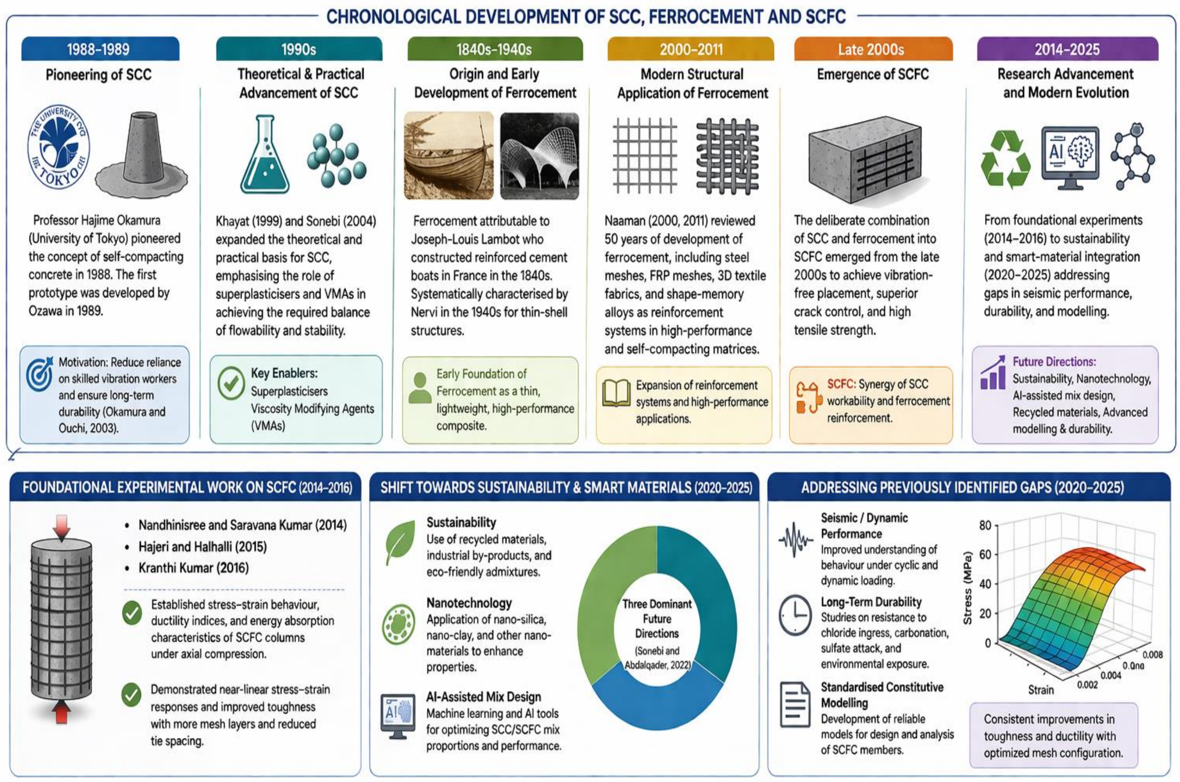
The combination of the two systems provides a highly workable, durable and strong building material. The main components of SCFC consist of the cement matrix (Ordinary Portland Cement OPC with supplementary cementitious materials (SCMs)), reinforcement system (meshes), chemical admixture system, and fine aggregate system. Ternary Blends with a mix of FA (30%) and SF (7.5%) have achieved compressive strengths over 68 MPa at 180 days [28]. Fine Aggregates consist of well graded River Sand or Manufactured Sand (M-Sand) with a maximum size of 4.75 mm. Recent research has explored alternative forms of sustainable reinforcement such as Vegetable-Fiber Grids produced from Alfa and Date-Palm fibers [4]. Chemical Admixtures are necessary for providing self-compacting properties to the composite material [5].

1.2 Key Structural Properties

SCFC has a number of excellent structural qualities beneficial to advanced construction techniques. It is characterized by being very fluid and can be poured into complex molds without vibrating, producing slumps as large as 650–750 mm in accordance with EFNARC guidelines [5]. Ferrocement reinforcement enhances ductility, especially in structural members (beams) that contain multiple layers of mesh providing significant energy absorbing capabilities [14]. Due to the close spacing of the reinforcement, SCFC provides excellent resistance to cracking and limits crack propagation [6], [7]. The durability of SCFC is yet another benefit, as the combination of low permeability microstructure and low W/C ratio results in less susceptibility to degradation from chemical attacks [1]. Finally, the process of placing SCFC eliminates the need for mechanical vibrations associated with conventional concrete placement methods [5]. (Figure 1.)

II. DEVELOPMENT AND EVOLUTION

The initial work on Self-Compacting Concrete was started by Prof. H. Okamura in 1988 at the University of Tokyo, followed by the first successful production of the SCC by Ozawa in 1989. Both were driven by an interest in providing a reliable method for placing concrete that would not require skilled vibration labor and could provide long-term durability of concrete structures [1]. Building upon this basic work, Khayat and Sonebi further extended the theoretical and practical base for SCC through the use of Super-Plasticizers (SP) and Viscosity Modifying Agents (VMAs) [2]. Ferrocement is attributed to Joseph Louis Lambot, who built reinforced cement boats in France in the 1840s. It was first systematically investigated by Nervi in the 1940s as a potential new structural system for the construction of thin shell structures. As documented by Naaman [14], over the last 50 years, ferrocement has been used for thin shell structures, steel mesh reinforcement, fibre-reinforced polymer (FRP) mesh reinforcement, three-dimensional textile fabric reinforcement, and even shape memory alloy reinforcement systems in self-compacting cement matrices. The recent emergence of SCFC can be traced back to the early 2000s. The initial experimentation related to SCC/ferrocement combinations was initiated by Nandhinisree and Saravana Kumar [17]; Hajeri and Halhalli [12]; and Kranthi Kumar [11], whose work established the stress-strain behavior, ductility index, and energy absorption capacity of SCFC columns subjected to axial compression. Sonebi and Abdalqader [2] conducted a review of the current state-of-the-art in SCC focused on nanotechnology, AI-assisted mix design, and recycled materials. (Figure 2.)



Professor Hajime Okamura (University of Tokyo) pioneered the concept of self-compacting concrete in 1988. The first prototype was developed by Ozawa in 1989.

Motivation: Reduce reliance on skilled vibration workers and ensure long-term durability (Okamura and Ouchi, 2003).

Khayat (1999) and Sonebi (2004) expanded the theoretical and practical basis for SCC, emphasising the role of superplasticisers and VMAs in achieving the required balance of flowability and stability.

Key Enablers:
Superplasticisers
Viscosity Modifying Agents (VMAs)

Ferrocement attributable to Joseph-Louis Lambot who constructed reinforced cement boats in France in the 1840s. Systematically characterised by Nervi in the 1940s for thin-shell structures.

Early Foundation of Ferrocement as a thin, lightweight, high-performance composite.

Naaman (2000, 2011) reviewed 50 years of development of ferrocement, including steel meshes, FRP meshes, 3D textile fabrics, and shape-memory alloys as reinforcement systems in high-performance and self-compacting matrices.

Expansion of reinforcement systems and high-performance applications.

The deliberate combination of SCC and ferrocement into SCFC emerged from the late 2000s to achieve vibration-free placement, superior crack control, and high tensile strength.

SCFC: Synergy of SCC workability and ferrocement reinforcement.

From foundational experiments (2014–2016) to sustainability and smart-material integration (2020–2025) addressing gaps in seismic performance, durability, and modelling.

Future Directions: Sustainability, Nanotechnology, AI-assisted mix design, Recycled materials, Advanced modelling & durability.

- Nandhinisree and Saravana Kumar (2014)
- Hajeri and Halhalli (2015)
- Kranthi Kumar (2016)

✓ Established stress–strain behaviour, ductility indices, and energy absorption characteristics of SCFC columns under axial compression.

✓ Demonstrated near-linear stress–strain responses and improved toughness with more mesh layers and reduced tie spacing.

Sustainability
Use of recycled materials, industrial by-products, and eco-friendly admixtures.

Nanotechnology
Application of nano-silica, nano-clay, and other nano-materials to enhance properties.

AI-Assisted Mix Design
Machine learning and AI tools for optimizing SCC/SCFC mix proportions and performance.

Seismic / Dynamic Performance
Improved understanding of behaviour under cyclic and dynamic loading.

Long-Term Durability
Studies on resistance to chloride ingress, carbonation, sulfate attack, and environmental exposure.

Standardised Constitutive Modelling
Development of reliable models for design and analysis of SCFC members.

Consistent improvements in toughness and ductility with optimized mesh configuration.

Figure 2. Development and Evolution of SCC, Ferrocement and SCFC.

III. LITERATURE REVIEW

The literature search was performed using a variety of sources and databases including Google Scholar, ResearchGate, Elsevier Science Direct, Springer Link, MDPI, PubMed Central, IJERT, IOSR JEN, and IJCRT. The searches were completed through late 2024. Using a combination of keywords relating to SCFC and SCC, a total of 28 articles met the inclusion criteria and were selected for the qualitative analysis. (Figure 3.)

3.1 Studies from 2020–2025 (Recent Advances)

Studies on ferrocement and self-compacting concrete (SCC) are becoming increasingly important. Gautam and Kumar [1] tested ferrocement panels and showed increased compressive strength with increased cement-to-binder ratios, demonstrating ferrocement's ability to resist fires and be environmentally friendly for lower-cost housing projects. Sonebi and Abdalqader [2] conducted an extensive literature review of SCC, emphasizing current trends such as AI-assisted mix design and incorporation of sustainable materials. As additional evidence, Ashefali and George [3] discovered that pre-fabricated hollow ferrocement beams exhibit better strength-to-weight ratios than pre-cast plain cement concrete (PCC) beams. Expanding into seismic applications, Chonratana and Chatpattananan [24] used ferrocement jacketing to improve structural performance by significantly increasing the resistance of columns, frames, and walls against earthquake forces—specifically, the columns resisted approximately 81%, frames approximately 14%, and walls approximately 19% more force. Sun et al. [25] utilized hybrid strengthening techniques combining steel bars or wire mesh with mortar (SWM), resulting in improved bearing loads without sacrificing ductility. Elsayed and Deifalla [26] noted that reinforcement with FRP meshes enhances ferrocement's fire-resistance and corrosion-resistance performance characteristics, though the thermal properties of FRP at elevated temperatures require further investigation. Onyelowe and Kontoni [27] noted there is no single rheological model for SCC, limiting the accuracy of predicting flow behavior in SCC. A 2025 study published in Scientific Reports [28] showed that SCC containing fly ash and silica fume can develop compressive strength >50 MPa and flexural strength >7 MPa simultaneously while adhering to all EFNARC specifications, with machine learning algorithms successfully predicting performance parameters.

3.2 Foundational Studies (2011–2019)

Hinge [4] investigated M45-grade SCC beams confined with ferrocement and reported a direct relationship between strength and strain of SCC and reduced spacing of ferrocement reinforcement. Tanawade and Modhera [5] using SCC-based ferrocrete slabs containing Fly Ash and GGBFS noted that acceptable compressive strengths are achieved regardless of specimen height-to-width ratio. Shaabana and Shaheen [6] found that lightweight ferrocement composite beams made from Expanded Metal Mesh exhibit excellent post-cracking behavior and energy absorption characteristics. Shaheen and Eltehawy [7] evaluated ferrocement channel slabs and noted greater stiffness, ductility, and load carrying capacity at less cost than conventional reinforced concrete. Dass and

Talwar [8] noted that ferrocement exhibits superior resistance to fire damage and lateral deflection, though performance depends heavily upon mesh layer thicknesses. Mohammed and Assi [9] developed a three-line tensile stress-strain model for ferrocement, providing a useful analytical tool for designing structures. Deepika and Srichandana [13] and Daniel et al. [14] supported the use of Polypropylene Fibers, Fly Ash, and Multiple Layers of Ferrocement to improve resistance to cracking and impact. Kranthi Kumar and Kranthi Kumar [11] observed nearly linear stress-strain behavior in ferrocement-confined SCC subjected to axial compression, along with increased toughness with additional confinement layers. Hajeri and Halhalli [12] and Nandhinisree and Saravana Kumar [17] noted similar increases in ultimate loads and ductility in ferrocement-confined columns. Khatuja et al. [18] presented one of the first constitutive models for ferrocement-confined SCC indicating that toughness increases almost directly proportional to confinement. Ashraf and Halhalli [19] and Deepa Shri and Thenmozhi [22] found that both steel fibers and hybrid fibers added to ferrocement mesh significantly increased flexural strength, deformation capacity, and crack control. Khan et al. [20] demonstrated that ferrocement layers are very effective at strengthening RCC beams in flexure. Sood et al. [15] found that fly-ash based self-compacting ferrocement panels reinforced with Geogrids exhibit better strength and corrosion resistance than traditional mesh-reinforced SCC panels. Sasiekalaa and Malathy [22] pointed out the role of Supplementary Cementitious Materials in increasing both mechanical properties and sustainability. The foundational work of Naaman [14] documented the historical development of ferrocement, including advances in reinforcement systems and cementitious composites, forming the theoretical basis for most current SCFC research.

Table 1: Summary and Comparison of Key Reviewed Studies on Ferrocement-Confined SCC (2011–2025).

Author (Year)	Specimen Size / Type	Concrete Grade / SCMs	Mesh Type	Loading Type	Key Outcome
Gautam & Kumar [1] (2022)	Ferrocement panels (precast)	Portland cement + fly ash	Welded / chicken wire	Compression	Cost-effective, fire-resistant; suitable for low-cost housing roofing
Sonebi & Abdalqader [2] (2022)	Review — SCC mix designs	SCMs + nanotechnology	N/A (SCC matrix)	Fresh + hardened	SCC advances: nanotechnology and AI-aided mix design
Ashefali & George [3] (2022)	Beams 0.4×0.25×1 m; t=50 mm	PCC / RCC fill	Single layer steel mesh	Load capacity	Hollow ferrocement beams adequate for low-cost housing; cost < RCC
Hinge [4] (2019)	Beams 150×150×750 mm (30 nos.)	M45 SCC	Welded wire mesh (1 layer)	Flexural	Linear strength-strain increase; vertical cracks at mid-span; analytical model proposed
Tanawade & Modhera [5] (2019)	Slabs 300–500×300×100 mm	SCC + fly ash + GGBFS	Welded wire mesh	Axial compression	300×300 mm slabs: highest strength due to lower slenderness ratio
Shaabana & Shaheen [6] (2018)	Beams 100×200×2000 mm (16 nos.)	Lightweight AAC concrete	Expanded metal + welded wire	Flexural	Expanded metal superior in post-cracking; energy absorption +64% vs control
Shaheen & Eltehawy [7] (2017)	U-slabs 500×100×2500 mm (10 nos.)	RC + ferrocement form	Metallic + fiberglass mesh	4-point bending	Improved ductility, crack resistance, energy absorption; lower cost than RC slabs
Mohammed & Assi [9] (2017)	Ferrocement discs	Various matrix grades	Wire mesh	Tensile / flexural	Trilinear stress-strain model; reliable for span/depth < 22
Kranthi Kumar [11] (2016)	Cylinders 150×300 mm	M30 SCC	GI mesh (multi-layer)	Axial compression	Near-linear stress-strain; ductility increases with mesh layers
Hajeri & Halhalli [12] (2015)	Columns Ø160×400 mm (6 nos.)	M40 SCC	Ferrocement shell + ties	Axial compression	Tie spacing controls ductility; ferrocement jacket enhances energy absorption

Nandhinisree & Kumar [17] (2014)	Columns Ø130×700 mm (6 nos.)	M40 SCC	Wire mesh + ties	Axial compression	Ferrocement confinement improves ductility and load-carrying capacity
Ashraf & Halhalli [19] (2013)	Slabs 700×300×40 mm (18 nos.)	SCC (EFNARC)	Welded mesh (1–2 layers)	Flexural	Steel fibres 0.5% + 2 mesh layers: maximum load capacity and rigidity
Naaman [14] (2011)	Review — thin composites (<50 mm)	Various	Steel mesh, FRP, 3D textiles	Review	50-year evolution; UHPFRC and SCC matrices enhance thin composites
Chonratana & Chatpattananan [24] (2023)	3-storey RC building	RC + ferrocement	Expanded metal mesh	Seismic	Columns improved by ≈81%; frames +14%; walls +19% over design value
Sun et al. [25] (2021)	RC columns (9 specimens)	Conventional RC	Steel bar/wire mesh mortar	Cyclic seismic	SWM jacketing: superior bearing capacity and ductile displacement
Elsayed & Deifalla [26] (2024)	Review — ferrocement	Various	Multiple mesh types incl. FRP	Review	FRP meshes enhance fire resistance and durability of ferrocement
Onyelowe & Kontoni [27] (2023)	Review — SCC rheological models	SCC with various SCMs	N/A	Rheological	Critical gap: no unified viscosity-yield stress model for sustainable SCC structures
Scientific Reports [28] (2025)	SCC with FA & SF	FA 20–40%, SF 5–10% + OPC	N/A (matrix study)	Compressive, tensile, flexural	FA30SF7.5 ternary blend: 68 MPa at 180 days; ML models predict CS with high accuracy

Note: SCC = Self-Compacting Concrete; SCFC = Self-Compacting Ferrocement Concrete; GGBFS = Ground Granulated Blast-Furnace Slag; EFNARC = European Federation of National Associations Representing for Concrete; FRP = Fibre Reinforced Polymer; SCMs = Supplementary Cementitious Materials; ML = Machine Learning; RC = Reinforced Concrete.

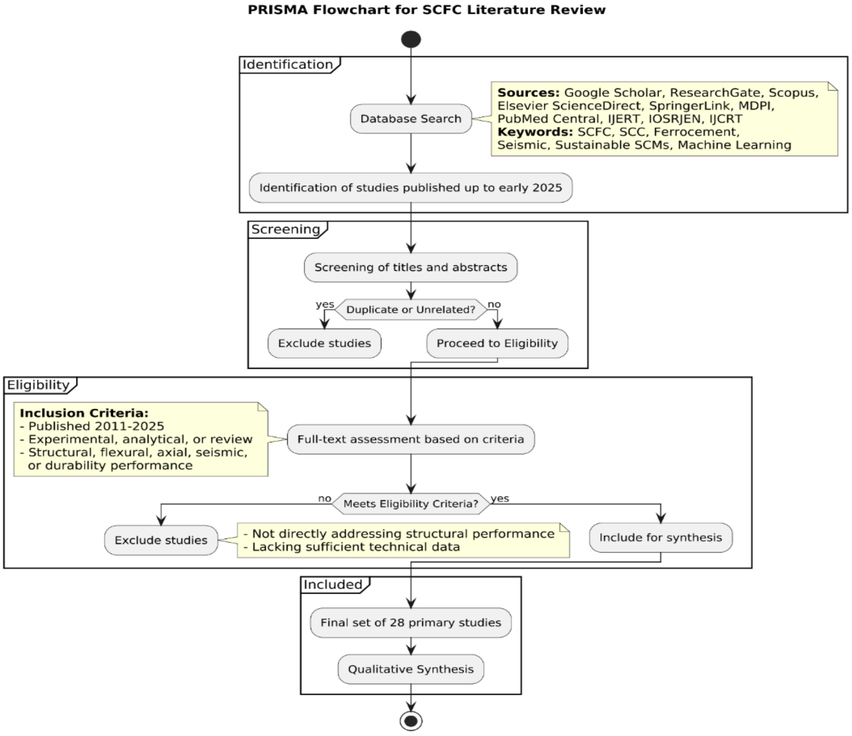


Figure 3. PRISMA Flowchart for SCFC Literature Review.

IV. RESEARCH GAPS IDENTIFIED

The following critical research gaps are identified from the synthesis of 28 reviewed studies. These gaps collectively represent the most significant barriers to the structural adoption and code-based design of SCFC in modern construction:

4.1 Long-term Durability and Environmental Behavior of SCFC

Most studies were conducted in laboratories under controlled environments and over short durations. The long-term behavior of SCFC exposed to aggressive environments such as chloride-induced corrosion, freeze-thaw cycles, sustained cyclic loads, and sulfate attacks is poorly understood. Accelerated durability testing protocols for SCFC test specimens must be established.

4.2 Seismic and Dynamic Behavior of SCFC

Some early works by Chonratana and Chatpattananan [24] and Sun et al. [25] investigated the seismic behavior of ferrocement-confined reinforced concrete members. However, experimental data concerning the cyclic response, hysteretic energy absorption, drift capacity, and failure modes of SCFC columns and frames subjected to seismic loadings are extremely scarce. As ferrocement jacketing emerges as an economically viable seismic retrofit solution, comprehensive experimental programs under simulated seismic loadings are needed.

4.3 Eco-friendly and Geopolymer-based Systems

Studies conducted recently [2], [28] have confirmed that ternary blends of supplementary cementitious materials (FA + SF) enhance the mechanical properties of high-performance self-compacting concretes. However, the integration of full alkali-activated or geopolymer-based binder systems into SCFC systems has yet to be experimentally proven. The mix design, fresh state workability, and compatibility of geopolymer with wire mesh reinforcements require further investigation.

4.4 Non-Metallic and Hybrid Mesh Reinforcement

Various alternative corrosion-resistant reinforcement materials to steel wire mesh—glass fiber mesh, vegetable fiber grid (Alfa, date-palm fibers), FRP mesh, polypropylene warp knitted fabric—have emerged. The structural performances of SCFC systems using these non-metallic meshes under combined loading conditions (axial + flexural + impact) and long-term bond characteristics between SCC matrix and non-metallic mesh reinforcements have never been thoroughly studied.

4.5 Fire Resistance and Thermal Behavior

Elsayed and Deifalla [26] consider fire resistance another significantly under-studied area. Ferrocement walls and panels are increasingly employed in low-cost housing due to their reported fire resistance [1]; however, the thermal behaviors of SCFC—particularly the effects of elevated temperature on mesh-mortar bonding characteristics, residual strength, and spalling—lack systematic experimental validation.

4.6 Computational Optimization and AI-assisted Design

Machine learning approaches for designing HPSCC mixes [28] are rapidly evolving; however, none of the reviewed studies explored applications to optimize SCFC-specific parameters, e.g., optimal mesh arrangement, mortar mix composition, and confinement geometry simultaneously. Finite element modeling of SCFC under different loading conditions using FE codes was also found to be limited in the reviewed literature.

V. DISCUSSION

The convergence of 28 studies published from 2011–2025 supports that ferrocement confinement improves the structural response of self-compacting concrete (SCC). All types of loading—axial compression, flexure, impact, and seismic—show improved load carrying capabilities, ductility, crack restraint, and energy absorbing capabilities compared to unconfined SCC. Therefore, SCC confined with ferrocement performs as a synergistic composite system rather than a simple summation of each component. The confinement action afforded by close-spaced wire meshes delays crack formation, restricts crack growth, and increases post-peak deformability under all loading conditions.This review identified three critical differences that can provide important information for designers. Firstly, the type of mesh used within SCFC appears to be highly dependent upon the primary failure mechanism. Expanded metal mesh performed best in flexural loading due to enhanced mechanical interlocking and crack bridging capability [6]. Conversely, hybrid mesh systems (chicken wire + welded mesh) were more effective at resisting impact loads due to progressive deformation and multiple crack arrest layers. Recent seismic performance testing [24], [25] extends the understanding of SCFC to include loading histories other than monotonically increasing, demonstrating that ferrocement confining jackets improve seismic resistance of RC columns via improved confinement, delayed spalling, and increased energy dissipation capacity.Integrating supplementary cementitious materials (SCMs), specifically fly ash (FA) and silica fume (SF), into SCC matrices is a sustainable method to achieve environmentally responsible SCFC systems [28]. Since the SCC matrix serves as the binder medium for the ferrocement mesh, its rheological and mechanical properties directly affect the efficiency of stress transfer and bonding development. One major limitation of the reviewed literature is the lack of standardized experimental methods. Differences in test specimen dimensions, curing conditions, mesh configurations, and testing protocols contribute to significant uncertainties in comparing results. The advent of machine learning (ML) methods in designing mixes of SCC [28] represents a paradigmatic shift with important implications for SCFC research. ML models such as ANN, ANFIS, and ELM have shown excellent predictive abilities for compressive strength as a function of mix components.

VI. CONCLUSION

In summary, this review has synthesized and critically reviewed 28 investigations into Self-Compacting Ferrocement Concrete (SCFC) produced between 2011 and 2025. It is evident that ferrocement confining of self-compacting concrete improves its structural behavior under both static and dynamic loading through improved load carrying capacity, ductility, energy absorption capabilities, and crack resistance. There appears to be a direct correlation between an increase in number of layers of mesh and optimized tie spacing's and the degree of improvement in structural behavior, indicating that confinement mechanisms can control the propagation of cracks and delay the occurrence of failure. Progress in recent years (2020–2025) indicates significant advancement in seismic performance sustainable materials, and data-driven mix design. Although there is evidence of advancement within this field, there are still significant research challenges remaining: the lack of constitutive models applicable to all SCFCs, limited understanding of long-term durability under adverse environmental conditions, and insufficient cyclic and dynamic testing. The greatest impediment to wider application of SCFC is the lack of standardization in design provisions and regulatory requirements. The most important initial research direction is to develop internationally recognized, performance-based design guidelines for SCFC members subjected to axial and flexural loads. Ultimately, a synergistic integration of SCC's superior workability and ferrocement's confinement efficiency along with new sustainable material innovations makes SCFC a potentially resilient and environmentally friendly building material.

ACKNOWLEDGMENT

The authors gratefully acknowledge the support of the Department of Civil Engineering, Oriental University, Indore. The authors also thank all colleagues and institutions that contributed to the body of knowledge reviewed in this paper.

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