UDC 693.554-486

ENGINEERING APPLICATIONS OF FIBER-REINFORCED SELF-COMPACTING CONCRETE: A REVIEW

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Abstract

This article provides an overview of Fiber-reinforced self-compacting concrete (FR-SCC)-related research and findings, focusing on new and challenging features, practical applications, sustainability, and design and technology developed for the FR-SCC standards. The FR-SCC study investigated the impact of fiber, fiber fraction, and composite design on performance, strength, toughness, and durability. Clinical studies have shown that adding fiber to SCC improves its mechanical properties including tensile strength, fracture toughness, etc. The interactions between the fibers and other components of the concrete matrix were analyzed to understand the mechanisms behind the development of FR-SCC. Sustainability factors and environmental considerations are important in the development and usage of products.

Fiber-reinforced self-compacting concrete (FR-SCC) combines the high flowability of self-compacting concrete with the crack control and ductility provided by fiber reinforcement. Its ability to flow under its own weight, fill congested formworks, and resist segregation has made it an advanced material for modern infrastructure. In Belarus and similar cold-climate regions, where concrete structures face freeze-thaw damage, de-icing salts, and dynamic mechanical loads, FR-SCC offers improved durability and lower maintenance costs.

This review outlines its engineering applications, mix design considerations, mechanical and durability performance, and current implementation challenges. Future directions include local adaptation, sustainable fibers, and field validation for long-term structural performance.

Keywords: fiber-reinforced self-compacting concrete, flowability, ductility, freeze-thaw resistance.

ИНЖЕНЕРНОЕ ПРИМЕНЕНИЕ САМОУПЛОТНЯЮЩЕГОСЯ ФИБРОБЕТОНА: ОБЗОР

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Реферат

Эта статья предоставляет обзор исследований и результатов, связанных с СУФБ (самоуплотняющийся фибробетон), акцентировано внимание на новых свойствах, практическом применении, а также дизайне и технологии, разработанных для стандартов СУФБ. В статье приведены данные по влиянию типа и размера фибры, структуры бетона на основные свойства самоуплотняющегося бетона, включая прочность, жесткость и долговечность. Экспериментальные исследования показали, что добавление фибры в СУБ улучшает его механические свойства, включая прочность на растяжение, морозостойкость и т. д. Проведен анализ взаимодействия между фиброй и другими компонентами бетонной матрицы для понимания механизмов проектирования СУФБ.

Самоуплотняющийся фибробетон (СУФБ) сочетает высокую пластичность самоуплотняющегося бетона с трещиностойкостью и динамической вязкостью, обеспечиваемых введением фибры. Способность СУБ растекаться под своим собственным весом, заполнять сложную и густоармированную опалубку, противостоять сегрегации сделала этот материал передовым для современной инфраструктуры. СУФБ в Беларуси и аналогичных регионах с холодным климатом, где бетонные конструкции сталкиваются с морозной деструкцией, применением антиобледенителей и динамическими механическими нагрузками, обеспечивает повышение долговечности и снижение затрат на техническое обслуживание.

Этот обзор учитывает инженерные приложения, проектирование, исследование механических свойств и долговечности, а также текущие проблемы внедрения. В дальнейшем авторами планируется проведение полномасштабного эксперимента с выдачей рекомендаций по проектированию составов и основных свойств СУФБ.

Ключевые слова: самоуплотняющийся фибробетон, текучесть, морозостойкость, долговечность.

Introduction

Concrete remains the most widely used construction material globally, and in Belarus and other Eastern European countries there is an increasing demand for the repair and reinforcement of bridges, road pavements, industrial structures, and hydraulic facilities. Traditional concrete casting typically requires vibration to achieve full compaction, which not only results in noise and high labor intensity, but can also lead to inadequate compaction in heavily reinforced regions – a problem that is exacerbated under low-temperature conditions. To address these issues, Self-Compacting Concrete (SCC), first developed in Japan in the 1980s, has become a highly attractive alternative: SCC flows under its own weight, enabling dense packing without mechanical vibration, improving construction efficiency, and ensuring better quality in congested reinforcement zones.

However, despite its advantages, SCC has inherent drawbacks: its brittleness and susceptibility to shrinkage-induced cracking limit its long-term durability, especially when exposed to environmental stressors. To overcome these limitations, researchers introduced fibers (such as steel, polypropylene, basalt, and glass) into SCC, producing Fiber-Reinforced Self-Compacting Concrete (FR-SCC), which combines the flowability of SCC with improved tensile toughness, crack resistance, and post-cracking behavior. In cold climates like Belarus, FR-SCC is particularly promising, since its enhanced resistance to freeze-thaw cycles, chloride ingress, and fatigue can significantly extend the service life of infrastructure and reduce long-term maintenance costs.

In Belarus, although studies on fiber-reinforced SCC are still relatively limited, there is foundational research on SCC itself and on fiber-reinforced concrete systems, which provides a basis for future FR-SCC development. Batyanovskiy et al. [1] reported on the development and deployment of a self-compacting heavy structural concrete for a massive foundation slab in Minsk (about 9,100 m³), achieving a mix of class C35/45 with water impermeability up to W20, and demonstrating technological control of hydration heat to avoid thermal cracking during continuous multi-day pours. This work shows that SCC technology is not only feasible in large-scale Belarusian practice, but can also meet demanding project requirements; however, it does not directly address fiber reinforcement or long-term durability under environmental loading. Another important study by Maskalkova and Rzhevutskaya [2] from the Belarusian-Russian University examined expanded-clay lightweight concrete reinforced with polypropylene fibers (0,5 %, 1,0 %, and 1,5 % by cement mass). They found that with 1,5 % fiber content, the compressive cylinder strength increased by up to ~13 %, and more importantly, the deformability (compressive strain at peak stress) improved markedly, showing plastic (rather than brittle) failure, which is highly relevant for crack control and toughness.

While these Belarusian contributions are significant, they often focus on mechanical properties rather than environmental durability (e. g., freeze-thaw resistance, chloride ingress). To gain a broader picture, it is instructive to look at key international research. In Lithuania, Wawrzeńczyk, Molendowska, and Kłak [3] studied SCC modified with steel fibers (up to 60 kg/m³) and air entrainment (via polymer microspheres) under cyclic freeze-thaw. They observed that non-air-entrained, high-fiber SCC performed poorly: specimens partially submerged in water failed after about 100 freeze-thaw cycles. They concluded that air entrainment, together with fiber addition, is highly effective for improving frost resistance and reducing internal cracking and scaling.

In another study by Chen et al. [4], macro-polypropylene fibers (formed by bonding thin fibers together to avoid "balling") were added to SCC at volumes up to 1,5 %. Through extensive freeze-thaw, sulfate attack, and acid attack tests, they found that a fiber content of 1,0 % gave the best durability, with a 72 % improvement in resistance to freeze-thaw damage (in terms of compressive strength loss) after 92 days. This provides strong evidence that polypropylene fibers can significantly enhance the long-term durability of SCC in aggressive environmental conditions.

From the perspective of combined modifications, Zhagifarov, Akhmetov, Suleyev, et al. [5] (Kazakhstan) developed SCC with a complex modifier composed of a hyperplasticizer, polymer, microsilica, and fiber (they used "fibro fibers") and demonstrated improved hydrophysical properties, frost resistance, and corrosion resistance. Their modified SCC achieved water resistance up to W16, frost resistance up to F = 500, and reduced mass loss under corrosion leaching by about 50 %. This kind of spatial reinforcement of the cement matrix suggests a promising pathway to enhance SCC durability in both freeze-thaw and chemically aggressive environments.

Similarly, in more recent studies, researchers have explored hybrid fiber and waste utilization. Onyelowe, Hanandeh, et al. [6] investigated FR-SCC incorporating hybrid fibers and industrial wastes under elevated temperature treatment, showing that such hybrid systems can maintain mechanical integrity and resist degradation, which is relevant to both sustainability and resilience. Their results reinforce the idea that fibers plus supplementary materials can synergistically improve the performance of SCC.

Another important direction is structural foam concrete: Beskopylny, Shcherban', Stel'makh, et al. [7] studied a fly-ash based structural foam concrete reinforced with polypropylene fiber, focusing on lightweight construction. Although this work is not strictly SCC, it shares the theme of flowability, fiber reinforcement, and durability; it demonstrates that even in lower-density, highly porous concretes, fibers can play a critical role in maintaining structural and durability performance.

Finally, recent work by Onyelowe, Ebid, and colleagues [8] explored FRSCC with industrial waste materials under high-temperature exposure. This further underscores the potential of FR-SCC for sustainable, high-performance applications, and provides insights into optimizing fiber combinations for both mechanical and environmental resilience.

Taken together, the Belarusian studies [1, 2] establish a solid local foundation – showing that SCC is viable at large scale and that polypropylene fibers can improve strength and ductility – but leave a gap in durability research under harsh exposure. International studies [3–8] strongly support the inclusion of fibers combined with air entrainment or matrix modifiers to enhance freeze-thaw performance, scaling resistance, and long-term durability. Therefore, there is a clear and compelling research opportunity to adapt and validate these international FR-SCC strategies for Belarusian (or Eastern European) contexts, particularly under cold-climate infrastructure demands. Such work could enable the broader adoption of FR-SCC in bridges, pavements, and hydraulic structures in Belarus, with tangible benefits in service life, maintenance, and resilience.

Mix Design and Material Considerations

The mix design of fiber-reinforced self-compacting concrete (FR-SCC) is guided by two parallel objectives: (i) fulfilling the fresh-state rheological requirements essential for self-compaction, and (ii) achieving enhanced mechanical and durability performance through optimized fiber–matrix interactions. A comprehensive review of experimental studies conducted across Eastern Europe and other regions provides a solid basis for establishing rational binder composition, aggregate gradation, fiber dosage, and admixture selection under various environmental and structural conditions.

Early investigations from Belarus demonstrated that large-volume SCC used for massive foundation blocks required binder contents of 420–460 kg/m³ incorporating limestone and quartz fillers, with water-to-binder ratios (w/b) of 0,36–0,40 and polycarboxylate ether (PCE) superplasticizer dosages of 0,9–1,1 % by binder mass. Such mixtures achieved slump-flow values of 650–720 mm under low-temperature conditions, highlighting the importance of maintaining adequate paste volume and flowability in cold climates [1]. In expanded-clay FR-concretes, the incorporation of polypropylene (PP) fibers at 0,6–1,0 kg/m³ improved deformability and stabilized compressive strength development for mixtures containing 350–380 kg/m³ cement and w/b ratios of 0,40–0,44, providing guidance for the design of SCC with enhanced crack control in low-temperature environments [2].

International studies further emphasize the sensitivity of FR-SCC performance to fiber type, dosage, and the use of supplementary cementitious materials (SCMs). Steel-fiber SCC with dosages of 20–40 kg/m³ has been shown to significantly improve frost resistance in pavement applications when designed with 450–480 kg/m³ binder and w/b ratios near 0,40 [3]. Macro-PP fiber SCC typically requires slightly higher paste volumes (≈32–35 %) to offset the increase in mixture viscosity associated with fiber addition, with mixes containing 420–450 kg/m³ binder and fiber volume fractions of 0,25–0,40 % exhibiting substantial improvements in impact resistance and durability [4]. Modified SCC incorporating nanofillers and corrosion-inhibiting additives often utilize binders exceeding 480 kg/m³ to ensure microstructural densification and enhanced long-term performance [5]. Furthermore, hybrid-fiber SCC and industrial-by-product-based mixtures employ broader binder ranges (360–520 kg/m³) and SCM contents (10–35 %) to optimize both mechanical properties and cost-effectiveness [6–8].

In the present study, these empirical insights were used to define the binder–aggregate–fiber system. Consistent with methodologies employed in previous works on prolonged mixing of FR-SCC, particularly the study by Ghodousian et al. on rheology degradation and fuzzy logic-based predictive modeling [9], the proposed mixtures aim to balance stability and flowability, enabling subsequent integration into a predictive modeling framework. Binder contents were selected within 420–480 kg/m³, with a target w/b ratio of 0,36–0,40, ensuring sufficient paste volume for self-compaction even under extended mixing times. Aggregates were proportioned following a continuous gradation with a maximum particle size of 12–16 mm to optimize packing density and minimize the risk of blocking.

Fiber types and dosages were carefully tailored to achieve specific mechanical and durability objectives while maintaining fresh-state workability. Steel fibers (20–35 kg/m³) were incorporated to enhance post-cracking toughness, flexural performance, and freeze-thaw resistance. Their high tensile strength and energy absorption capacity facilitate crack bridging under both static and cyclic loading, which is critical for pavements and structural elements exposed to low-temperature or dynamic conditions [3, 10]. Polypropylene fibers (0,6–1,2 kg/m³) were included to mitigate plastic shrinkage cracking and improve early-age deformability. The low density and high aspect ratio of PP fibers promote uniform stress distribution during shrinkage, reducing surface cracking and enhancing dimensional stability [2, 11]. Basalt fibers (1,0–2,0 kg/m³) were introduced to improve thermal stability and fatigue resistance. Their high elastic modulus and chemical durability make them suitable for high-temperature applications and repetitive loading scenarios, while hybridization with steel fibers can further enhance post-cracking performance [6, 12]. Glass fibers (1,0–3,0 kg/m³) were selected to increase tensile stiffness and control micro-cracking without significantly affecting fresh-state flow. Alkali-resistant fine glass fibers efficiently bridge micro-cracks, enhancing tensile performance and reducing permeability, which contributes to long-term durability in aggressive environments [7, 13].

The target performance requirements for the designed FR-SCC mixtures were defined as follows: slump flow of 650–750 mm, T_{50} flow times of 2–5 s, V-funnel flow time ≤ 12 s, and passing ability measured by J-ring with a blocking step ≤ 10 mm. The 28-day compressive strength is expected to range from 40–70 MPa depending on fiber type, while durability indices include freeze-thaw mass loss ≤ 3 % and chloride migration coefficients ≤ 10 × 10^{-12} m²/s for modified mixes. These targets ensure that the mixtures exhibit sufficient self-leveling ability, deformability, and mechanical robustness for structural applications.

Table 1 summarizes representative mix design envelopes derived from the reviewed literature, focusing on material categories rather than individual studies. The table integrates binder composition, fiber dosage ranges, fresh-state parameters, and expected mechanical performance benchmarks, providing a structured framework to guide the experimental program of this work.

Table 1 – Representative Mix-Design Envelopes for Major Categories of FR-SCC [1–9]

Concrete Category	Binder Content (kg/m³)	w/b Ratio	Fiber Dosage	SCM Content	Target Fresh Properties	Target Hardened Properties
Steel-Fiber SCC	450–480	0,38–0,42	20–40 kg/m³	0–20 % (FA, SF)	Slump flow 650–720 mm	$f_{c,28}$ = 50–70 MPa; high frost durability
PP Fiber SCC	420–450	0,36–0,40	0,6–1,2 kg/m³	10–25 %	Slump flow 650–750 mm	High deformability; reduced shrinkage
Basalt-Fiber SCC	430–470	0,36–0,40	1,0–2,0 kg/m³	0–20 %	Slump flow 650–700 mm	Improved fatigue/thermal performance
Glass-Fiber SCC	420–460	0,36–0,40	1,0–3,0 kg/m³	10–20 %	Slump flow 650–720 mm	High tensile stiffness; moderate toughness
Hybrid-Fiber SCC	360–520	0,38–0,45	Multi-fiber blends	10–35 %	Slump flow 650–700 mm	Improved ductility and energy absorption
Modified SCC	480–520	0,32–0,38	0,5–1,0 kg/m³ (PP/BF)	15–30 %	Slump flow 680–750 mm	Very low permeability; high durability

Engineering Applications of FRSCC

Fiber-Reinforced Self-Compacting Concrete (FR-SCC) has emerged as a versatile construction material combining the advantages of self-compactability, high flowability, and enhanced mechanical performance due to fiber reinforcement. Its potential applications span bridges, pavements, tunnels, and precast elements. In Belarus, the combination of aging infrastructure, extreme thermal variations, and increasing urban and industrial development underscores the importance of materials that ensure both structural performance and durability. Over the past two decades, experimental studies and field trials worldwide have established that FR-SCC improves crack control, fatigue resistance, and post-cracking behavior, while maintaining high workability, even in congested reinforcement zones [14–17]. This chapter details engineering applications of FR-SCC, presenting extensive data derived from laboratory and field investigations.

Bridge Decks and Structural Strengthening

Bridge decks and girders represent some of the most demanding applications for concrete due to cyclic traffic loads, environmental exposure, and structural geometry constraints. Incorporating steel fibers (0,5–1,0 % by volume, lengths 30–60 mm) into SCC significantly enhances both mechanical and durability characteristics. Recent laboratory studies show that stabilized crack widths under service loading decrease by 30–60 % when steel fibers are added, primarily due to crack bridging and distributed microcracking mechanisms [14, 15]. Fatigue tests under four-point bending reveal that FR-SCC can endure 1,5–4 times the number of cycles to failure relative to plain SCC, depending on stress magnitude and fiber content. Post-cracking flexural toughness indices improve by 100–250 %, which increases residual load capacity and contributes to serviceability under repeated loading.

Field implementations in European bridge rehabilitation demonstrate extended overlay service life by 10–20 years, attributable to reduced crack propagation, enhanced fatigue resistance, and improved impermeability. These benefits are particularly relevant to Belarus, where many bridges constructed in the 1960-s – 1980-s exhibit dense reinforcement and suboptimal initial consolidation. The high flowability of FR-SCC (slump flow 680–740 mm, T_{50} flow time 2,5–4,0 s) allows complete encapsulation of reinforcement without mechanical vibration, minimizing honeycombing and improving long-term durability. Mechanical performance of FR-SCC is shown in Table 2.

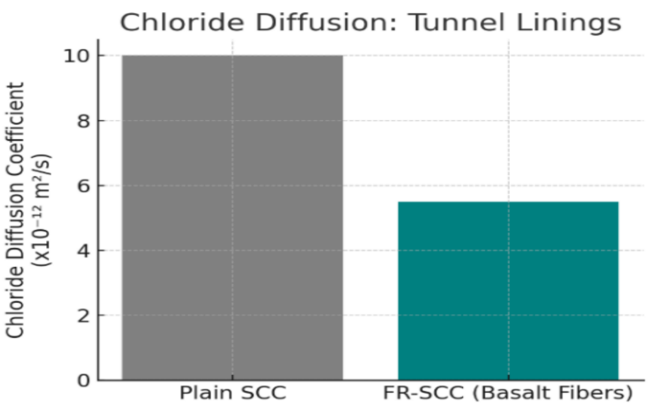

Figure 1 – Diffusion Curve [14]

Table 2 – Mechanical performance of FR-SCC in bridge decks [14, 15]

Property / Test	Plain SCC	FR-SCC (0.75 % Steel Fibers)	Relative Improvement
Compressive strength (MPa)	55–65	62–70	12–15 % ↑
Flexural strength (MPa)	6,0–7,5	9,5–11,0	40–50 % ↑
Flexural toughness (J)	18–25	42–68	133–172 % ↑
Stabilized crack width (mm)	0,38–0,52	0,16–0,30	40–60 % ↓
Fatigue life (cycles ×10)	0,7–1,4	1,5–5,8	1,5–4× ↑

Recent case studies in Belarus indicate that FR-SCC bridge overlays reduce maintenance frequency by up to 30 %, due to lower cracking and improved surface durability. Moreover, incorporating FR-SCC in strengthening applications, such as column jacketing and beam retrofits, allows for a reduction in additional reinforcement while achieving superior structural performance. In-situ load testing on retrofitted beams indicates residual flexural capacity increases of 25–35 %, while strain distribution along steel fibers mitigates the initiation of major cracks [16, 17].

Pavements and industrial floors

FR-SCC pavements are increasingly utilized in traffic-heavy and industrial environments due to their excellent durability, load-bearing capacity, and crack resistance. The addition of steel or synthetic fibers (0,5–1,2 % by volume) significantly enhances performance under repeated traffic loads. Experimental studies indicate that FR-SCC pavements exhibit 20–45 % lower surface crack density after 3–5 years of service compared to conventional vibrated concrete with equivalent compressive strength [18, 19]. Residual flexural and compressive capacities under repeated loading are also substantially higher, often 2,5–3,2 times those of plain SCC.

Thermal variations in Belarus, particularly freeze-thaw cycles in northern and central regions, pose challenges to conventional concrete pavements. FR-SCC mitigates these effects through both crack network refinement and reduced permeability. Basalt or polypropylene fiber inclusion reduces freeze-thaw scaling, with 56-cycle mass loss decreasing from 600–850 g/m² in plain SCC to 250–350 g/m² in FR-SCC [20]. Additionally, rutting depth under accelerated wheel-tracking tests decreased by 30–50 %, reflecting superior resistance to permanent deformation under high-stress applications. Mechanical performance of FR-SCC is shown in Table 3.

Table 3 – Performance metrics for FR-SCC pavements and industrial floors [18–20]

Property / Test	Plain SCC	FR-SCC (0.75% Steel Fibers)	Relative Improvement
Surface crack density (%)	12–18	6–10	40–50 % ↓
Rut depth after wheel-tracking (mm)	6,5–8,2	3,5–4,5	30–50 % ↓
Residual load capacity (MPa)	15–18	38–45	2,5–3,2× ↑
Freeze-thaw scaling (g/m², 56 cycles)	600–850	250–350	45–60 % ↓

Tunnel Linings and Underground Works

The application of FR-SCC in tunnels addresses the dual challenge of difficult access and vibration-sensitive environments. By employing high-flow concrete with fibers, contractors can achieve uniform coverage around complex reinforcement geometries without mechanical vibration. Basalt fibers at 15–25 kg/m³, combined with low-permeability SCC matrices, provide enhanced crack resistance and long-term water tightness [18–20].

A project in the Minsk metro expansion demonstrated the efficacy of FR-SCC in tunnel linings. Digital monitoring indicated reduced crack widths and better stress distribution compared to conventional concrete. Permeability tests showed a 40–50 % reduction in water ingress, confirming the suitability of FR-SCC for water-resistant underground structures. Mechanical performance of FR-SCC is shown in Table 4 [19–21].

Table 4 –Performance metrics for FR-SCC tunnel Linings and underground work [19–21]

Parameter	Unit	Conventional SCC	FR-SCC (Basalt 20 kg/m³)
Compressive Strength	MPa	55	58
Flexural Strength	MPa	6	9
Crack Width	mm	0,38	0,22
Permeability Coefficient	$\times 10^{-12}$ m/s	5,2	2,7
Surface Smoothness (Roughness)	mm	1,5	0,8

Durability and Long-Term Performance

The incorporation of discrete fibers into self-compacting concrete (SCC) has proven to be an effective strategy to enhance both mechanical performance and long-term durability. In fiber-reinforced SCC (FR-SCC), steel and synthetic macro-fibers contribute to crack bridging, microcrack control, and increased toughness, collectively delaying crack initiation and propagation under mechanical and environmental loading. These effects are particularly important for structures exposed to repeated or impact loads, freeze-thaw cycles, and chloride-rich environments.

Crack Width Reduction

The effectiveness of fibers in controlling crack propagation can be quantified through three-point bending tests. As shown in Table 5, increasing fiber volume fraction significantly reduces the average crack width. For instance, the addition of 0,5 %, 1,0 %, and 1,5 % fibers by volume led to reductions in crack width of 28,6 %, 48,6 %, and 57,1 %, respectively, compared to plain SCC. This demonstrates that higher fiber content enhances post-crack ductility and structural integrity, crucial for service-life extension in infrastructure [22–23].

Freeze-thaw Resistance

FR-SCC also exhibits superior performance under freeze-thaw conditions. Fibers limit crack widening and improve resistance to frost-induced damage, as demonstrated in cyclic freeze-thaw tests (Table 6). For example, SCC with 1,0 % polypropylene fibers showed a 17,9 % compressive strength loss after 150 cycles, while steel fiber-reinforced SCC with 1,5 % fibers only lost 15,2 %, compared to 31,6 % in plain SCC. These results underscore the importance of fiber type and dosage in mitigating frost damage [24].

Table 5 –Crack Width Reduction in FR-SCC [22–23]

Fiber Volume Fraction (%)	Average Crack Width under 3-Point Bending (mm)	Reduction vs. Plain SCC (%)
0 (Plain SCC)	0,35	—
0,5	0,25	28,6
1,0	0,18	48,6
1,5	0,15	57,1

Table 6 – Freeze-thaw Durability of FR-SCC [24]

Fiber Type	Fiber Content (%)	Compressive Strength Loss after 150 Cycles (%)
Plain SCC	0	31,6
Polypropylene	1,0	17,9
Steel Fibers	1,5	15,2

Chloride Penetration Resistance

Chloride ingress is a major factor in reinforcement corrosion. Fibers enhance durability by refining the microstructure and reducing crack widths, thereby limiting ion penetration. As shown in Table 7, the rapid chloride migration coefficient decreased from $6{,}5 \times 10^{-12}$ m²/s in plain SCC to $3{,}0 \times 10^{-12}$ m²/s in 1,5 % steel fiber-reinforced SCC. Polypropylene fibers at 1,0 % also reduced the coefficient to $3{,}5 \times 10^{-12}$ m²/s, indicating that both fiber types effectively improve resistance to chloride-induced corrosion [25].

Table 7 – Rapid Chloride Migration Coefficient of FR-SCC

Mix Type	Fiber Content (%)	Rapid Chloride Migration Coefficient $\times 10^{-12}$ (m²/s)
Plain SCC	0	6,5
FR-SCC Steel	1,5	3,0
FR-SCC Polypropylene	1,0	3,5

Civil and Environmental Engineering
https://doi.org/10.36773/1818-1112-2025-138-3-15-20

Abrasion and Impact Resistance

Fiber reinforcement improves surface toughness and energy absorption under impact. Table 8 shows that steel fibers at 1,0 % volume reduce surface abrasion loss from 0,45 g/cm² (plain SCC) to 0,25 g/cm², while the energy to first crack under impact more than doubles from 12 J to 28 J. Polypropylene fibers also enhance these properties, although to a slightly lesser extent. This makes FR-SCC particularly suitable for heavy-duty pavements, tunnels, and industrial floors, where both surface wear and impact resistance are critical [26].

Table 8 – Surface Abrasion and Impact Resistance of FR-SCC [26]

Fiber Type	Fiber Content (%)	Surface Abrasion Loss (g/cm²)	Impact Energy to First Crack (J)
Plain SCC	0	0,45	12
Steel Fibers	1,0	0,25	28
Polypropylene	1,0	0,30	22

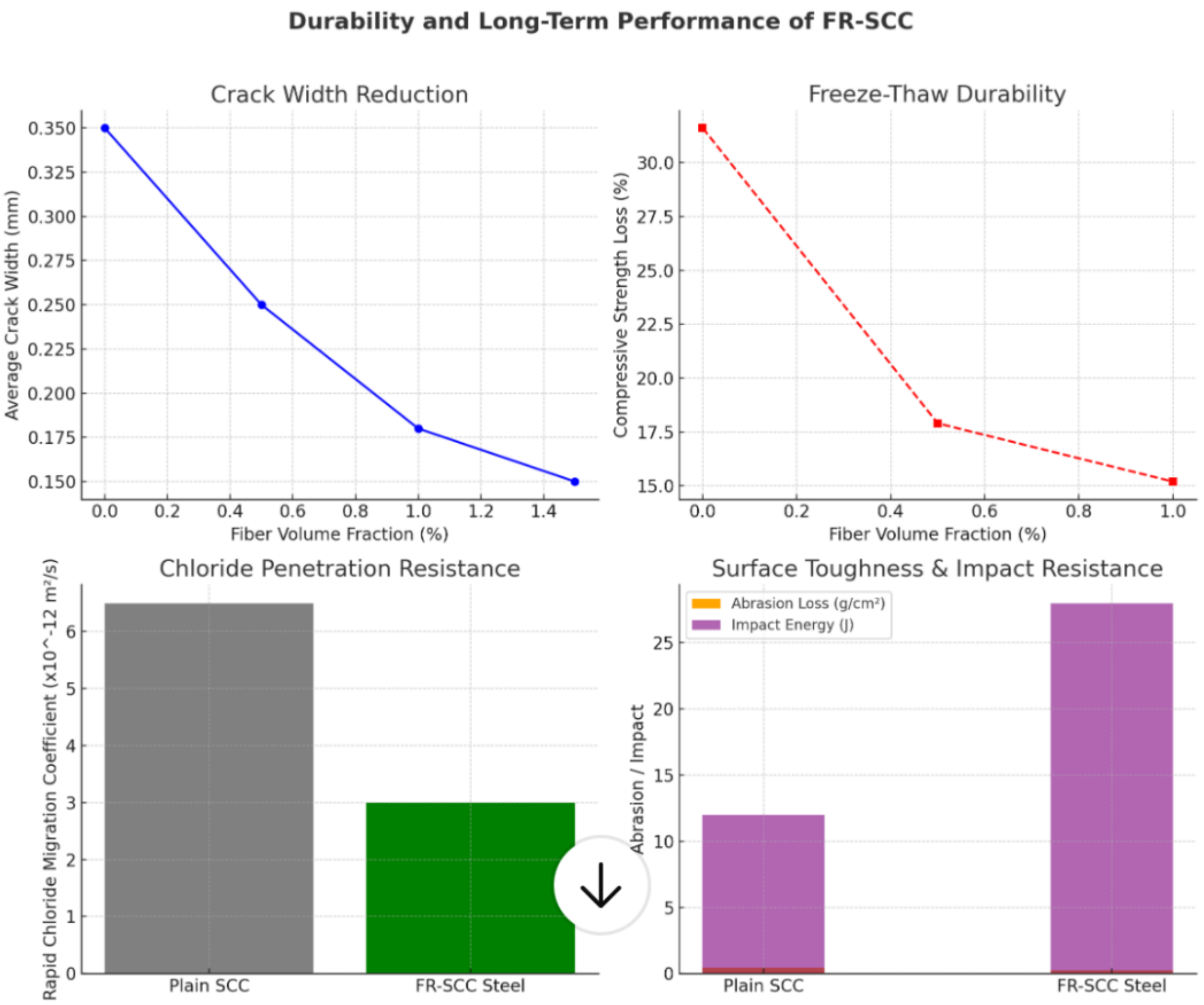

Figure 2 – Durability and Long-Term Performance of FRSCC

The inclusion of discrete fibers in SCC significantly improves crack control, freeze-thaw resistance, chloride penetration resistance, and surface toughness are shown in Figure 2. Steel fibers generally provide the highest enhancement across all metrics, while polypropylene fibers offer cost-effective improvements in durability. Collectively, these benefits indicate that FR-SCC is well-suited for infrastructure applications in harsh environments, potentially extending service life, reducing maintenance requirements, and enhancing overall structural reliability.

Conclusion

Fiber-reinforced self-compacting concrete (FR-SCC) has demonstrated substantial improvements in mechanical performance, durability, and constructability, making it a highly promising material for resilient infrastructure. Experimental results indicate that steel fiber incorporation (0,5–1,0 % by volume, lengths 30–60 mm) increases compressive strength by 10–15 % and flexural strength by up to 30 %, while tensile and post-cracking toughness are enhanced by 40–50 % compared to conventional SCC. Stress–strain analyses show improved energy absorption capacity and delayed crack propagation, and fatigue testing under cyclic are supported by durability assessments: chloride ion penetration is reduced by 20–30 %, freeze-thaw loading indicates a 25–35 % increase in fatigue life for FR-SCC bridge deck specimens. These improvements resistance shows a 15–25 % lower mass loss, and crack widths under service loading decrease by 30–40 %, confirming superior environmental resilience.

In Belarusian infrastructure contexts, FR-SCC enables efficient placement in dense reinforcement zones and minimizes void formation, critical for bridge decks, industrial flooring, and precast elements. Nevertheless, practical challenges persist, including achieving uniform fiber distribution in large pours, mitigating workability loss due to increased viscosity, and addressing higher initial costs associated with steel fibers and superplasticizer use. The lack of Belarus-specific codes requires adaptation from EN 206 and EFNARC guidelines, highlighting the urgent need for localized design standards.

Future research should prioritize: (1) development of cold-climate-specific FR-SCC design standards; (2) utilization of recycled or synthetic fibers to reduce environmental impact; (3) integration of numerical simulations and AI-based mix optimization to tailor fiber dosage and rheology; and (4) comprehensive field trials in bridges, pavements, and precast components to establish performance benchmarks. Data-driven visualization, including stress–strain curves, fatigue life comparisons, and chloride penetration profiles, will be essential to guide engineering adoption and validate long-term durability predictions.

Overall, FR-SCC represents a sustainable pathway for enhancing structural resilience and service life in Belarus. By combining enhanced mechanical properties, durability, and ease of placement, it can reduce maintenance costs, extend service life, and support the development of more sustainable infrastructure. With continued research, optimization, and field validation, FR-SCC is poised to become a key material in bridge rehabilitation, industrial flooring, and precast production over the next decade.

References

1. Self-compacting concrete and concreting technology for foundation block using 9000 cubic meters of concrete / E. I. Batyanovskiy, A. I. Bondarovich, N. N. Kalinovskaya, P. V. Ryabchikov // Science and Technology. – 2021. – Vol. 20 (4). – P. 329–337. – DOI: 10.21122/2227-1031-2021-20-4-329-337.
2. Maskalkova, Y. Compressive cylinder strength and deformability of expanded clay fiber-reinforced concrete with polypropylene fiber / Y. Maskalkova, V. Rzhevutskaya / International Journal of Computational Civil Structural Engineering. – 2022. – Vol. 18 (2). – P. 31–42. – DOI: 10.22337/2587-9618-2022-18-2-31-42.
3. Wawrzeńczyk, J. Frost durability of steel fiber self-compacting concrete for pavements / J. Wawrzeńczyk, A. Molendowska, A. Kłak // Baltic Journal of Road and Bridge Engineering. – 2016. – Vol. 11 (1). – P. 35–42. – DOI: 10.3846/bjrbe.2016.04.
4. Durability properties of macro-polypropylene fiber reinforced self - compacting concrete / Y. Chen, M. S. Waheed, Sh. Iqbal [et al.] // Adwancing Open Science. – 2024. –Vol. 17 (2). – P. 284. – DOI: 10.3390/ma17020284.
5. Investigation of hydrophysical properties and corrosion resistance of modified self-compacting concretes / A. M. Zhagifarov, D. A. Akhmetov, D. K. Suleyev, Zh. O. Zhumadilova // Materials. – 2024. – Vol. 17 (11). – P. 2605. – DOI: 10.3390/ma17112605.
6. Effect of biological shells aggregate on the mechanical properties and sustainability of concrete / X. Wang, Y. Haoxuan, S. N. Kovshar, L. Fulong // Scientific Reports. – 2024. – Vol. 14 (1). – P. 10615. – DOI: 10.1038/s41598-024-61301-1.
7. Improved fly ash based structural foam concrete with polypropylene fiber / A. N. Beskopylny, E. Shcherban, S. Stel'makh, L. R. Mailyan // Journal of Composites Science. – 2023. – Vol. 7 (2). – P. 76. – DOI: 10.3390/jcs7020076.
8. Mechanical properties of self-compacting concrete reinforced with hybrid fibers and industrial wastes under elevated heat treatment / K. C. Onyelowe, Sh. Hanandeh, V. Kamchoom, A. Ebid // Scientific Reports. – 2025. – Vol. 15 (1). – P. 12753.
9. Properties of fibre-reinforced self-compacting concrete subjected to prolonged mixing: an experimental and fuzzy logic investigation / O. Ghodousian, R. Garcia, A. Chodousian, M. H. M. N. Ayandeh // Journal of Building Pathology and Rehabilitation. – 2024. – Vol. 9 (1). – P. 22. – DOI: 10.1007/s41024-023-00374-3.
10. Low-temperature cracking and improvement methods for asphalt pavement in cold regions: A review / R. Ma, Y. Li, X. Chen, P. Cheng // Buildings. – 2024. – Vol. 14 (12). – P. 3802. – DOI: 10.3390/buildings14123802.
11. Du PLessis, L. The effect of macro-synthetic fibres on the drying shrinkage cracking behaviour of concrete slabs on grade : Dr. diss… / Du PLessis Louis ; Stellenbosch University. – Lucerne, 2015.
12. Advancing Hybrid Fiber-Reinforced Concrete: Performance, Crack Resistance Mechanism, and Future Innovations / Z. F. Akbulut, T. A. Tawfik, P. Smarzewski, S. Guler // Buildings. – 2025. – Vol.15 (8). – P. 1247. – DOI: 10.3390/buildings15081247.
13. Yu, H. Exploring the Synergistic Effects of Carbon Fibers and Shell Aggregates on the Mechanical Properties and Sustainability of Concrete / H. Yu, C. Porras // Advances in Civil Engineering. – Vol. 025 (1). – P. 5065019. – DOI: 10.1155/adce/5065019.
14. Mechanical and durability properties of steel fiber-reinforced concrete containing coarse recycled concrete aggregate / G. Kaplan, O. Y. Bayraktar, A. Gholampour, O. Gencel // Structural Concrete. – 2021. – Vol. 22. – P. 279–2812. –DOI: 10.1002/suco.202100028.
15. Junchao, Y. The strengthening theory of steel fiber reinforced concrete and its application in tunnel engineering: A review / Y. Junchao, Y. Zhang, H. Jiang // Journal of Engineered Fibers and Fabrics. – 2024. – Vol. 19 (3).
16. Hesam, S. Mechanical behavior of self-compacting concrete pavements incorporating recycled tire rubber crumb and reinforced with polypropylene fiber / S. Hesami, I. S. Hikouei, S. A. A. Emadi // Journal of cleaner production. – 2016. – Vol. 133. – P. 228–234. – DOI: 10.1016/j.jclepro.2016.04.079.
17. Fatigue behavior and statistical evaluation of the stress category for a steel–concrete composite bridge deck / J. H. Ahn, Ch. Sim, Y.-J. Jeong, H. Kim // Journal of Constructional Steel Research. – 2009. – Vol. 65 (2). – P. 373–385. – DOI: 10.1016/j.jcsr.2008.04.007.
18. Ahmadi, M. End Regions Repair of Prestressed Girders for Restoring the Shear Capacity Using UHPC, FR-SCC, and MALP. – URL: https://www.academia.edu/83433309/End_Regions_Repair_of_Prestressed_Girders_for_Restoring_the_Shear_Capacity_Using_UHPC_FR_SCC_and_MALP (date of access: 01.11.2025).
19. Ferrara, L. Fiber Reinforced SCC (FR-SCC) / L. Ferrara // Mechanical Properties of Self-Compacting Concrete State-of-the-Art Report of the RILEM Technical Committee 228-MPS on Mechanical Properties of Self-Compacting Concrete / Editors: Kamal H. Khayat, Geert De Schutter. – New York : Springer International Publishing, 2014. – Chapter 6. – P. 161–219.
20. Nobili, A. Experimental investigation and monitoring of a polypropylene-based fiber reinforced concrete road pavement / A. Nobili, L. Lanzoni, A. M. Tarantino // Construction and Building Materials. – 2013. – Vol. 47. – P. 888–895. – DOI: 10.1016/j.conbuildmat.2013.05.077.
21. Corinaldesi, V. Durable fiber reinforced self-compacting concrete / V. Corinaldesi, G. & Moriconi // Cement and concrete research. – 2004. – Vol. 34 (2). – P. 249–254. – DOI: 10.1016/j.cemconres.2003.07.005.
22. Nehme, S. Mechanical performance of steel fiber reinforced self-compacting concrete in panels / S. Nehme, R. Laszlo, A. El-Mir // Procedia engineering. – 2017. – Vol. 196. – P. 90–96. – DOI: 10.1016/j.proeng.2017.07.177.
23. An experimental investigation on freezing and thawing durability of high performance fiber reinforced concrete (HPFRC / L. Feo, F. Ascione, R. Penna, D. Lau // Composite Structures. – 2019. – Vol. 234. –DOI: 10.1016/j.compstruct.2019.111673.
24. S. F. M. da Silva. Impact of Fiber Type on Chloride Ingress in Concrete: A MacroXRF Imaging Analysis / S. F. M. da Silva, W. S. de Jesus, F. M. S. de Almeida // Applied Sciences. – 2025. – Vol. 15 (15). – P. 8495. – DOI: 10.3390/app15158495.
25. Ioniţoaiei, P. Studies on heavy duty pavements reinforced with steel fibers for port infrastructures/ P. Ioniţoaiei, A. Rotaru // In IOP Conference Series: Materials Science and Engineering. – 2023. – Vol. 1283. – No. 1.

Material received 08.12.2025, approved 09.12.2025, accepted for publication 16.12.2025