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A Review of the Combined Effect of Recycled Steel Fibers and Waste Nano Glass On the Technical Performance of Self-Compacting Concrete

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Abstract: There are many advantages to using fibers in self-compacting concrete (SCC) in terms of their structural behavior or mechanical properties, but the porosity in all types of concrete is still a major problem. Thus, continuous research is needed to find solutions to reduce these pores and improve their strength and durability. Self-compacting concrete's (SCC) performance has been greatly enhanced using nanomaterials and recycled steel fibers, however, there are still many unanswered questions to explore their potential fully. The majority of current research focuses on recycled fibers or nanomaterials, with little investigation into how these two elements work together to affect the mechanical properties and durability. It found that the purpose of adding nanomaterials to fibrous concrete is to improve the microstructure, including the interfacial transition zone (ITZ) because it reduces the porosity and boosts hydration products, which will increase the amount of Calcium Silicate Hydrate (C-S-H) gel. In contrast, steel fibers enhanced the mechanical properties of self-compacting concrete and avoided undesirable brittle failure. This work attempts to improve the performance of SCC using a combination of steel fibers taken from scrap tires with nano glass that is taken from the waste of glass. The impacts of fibers and nanomaterials on the structural behavior and mechanical characteristics of SCC were reviewed separately, and then studied their combined effect. Finally, the review recommends adding the nano glass as a partial replacement for cement to benefit from the silica found in the glass composition, which is expected to increase the hydration products and reduce the porosity, because the pozzolanic interaction of glass becomes very active when it reaches a smoothness of (75 µm) due to the increase in surface area. On the other hand, it will improve the bonding strength between steel fibers and cement paste, increasing the ductility and improving the structural behavior to help minimise the brittle fracture and, thus, the associated risks.

Keywords: Self-compacting concrete, nanomaterials, recycled steel fibers, porosity reduction, mechanical properties

Introduction

For many years, concrete has been a key factor in industrial buildings due to its durability and affordability. However, compacting techniques and conventional casting have drawbacks, especially for structures with complex reinforcement or molds. These impediments may reduce the efficacy and durability of concrete structures (1). Self-compacting concrete (SCC) has become a cutting-edge technique to address these problems and improve the quality and durability of concrete constructions. SCC was first used in Japan in 1988, then in the 1990s, it was brought to Europe through Sweden (2). This revolutionary concrete blend possesses the capability to flow effortlessly into complex and detailed formwork without requiring mechanical vibration, even in heavily reinforced segments. There are several advantages to using SCC, including lower labor costs, improved surface polish, quicker building timelines, and less noise pollution. The main components of self-compacting concrete are cement, aggregate (fine and coarse), water, and admixtures (3).

Fibrous SCC has gained attention recently due to its improved structural behavior and mechanical properties. Fiber integration into SCC can improve its strength and durability while resolving problems of porosity in concrete constructions. Furthermore, adding nanoparticles to fibrous SCC as a supplement shows promise for improving its functionality even more. Investigating and experimentally testing the effectiveness of fibrous self-compaction concrete that incorporates nanomaterials can provide important information on the potential benefits of this cutting-edge strategy for environmentally friendly building practices (1, 3, 4).

Even though the need for sustainable construction materials is on the rise, research into the impacts of incorporating recycled steel fibers and Nano glass in SCC is still relatively nascent.

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Although earlier studies have looked into the separate effects of RSF and nanomaterials on SCC, there is a scarcity of research addressing their combined impact on concrete composites, where numerous studies suggest that steel fibers can improve both toughness and ductility, whereas using nano glass might enhance compressive strength and lower porosity due to its pozzolanic characteristics. Nonetheless, there is a lack of empirical evidence on the interaction between these two components within a shared matrix. For example, excessive amounts of either additive could lead to clumping problems, which would hinder workability and overall performance (5, 6), however, this interaction has not been thoroughly explored. Thus, there is a pressing need for methodical research that evaluates not only mechanical properties but also their ductility, structural behavior, and bonding strength between steel fibers and cement paste when both materials are utilized together.

Furthermore, investigating different dosages and combinations could identify optimal mixing strategies that improve performance while minimizing potential disadvantages.

The existing uncertainty about the relationship between steel fibers and nano glass in SCC poses a challenge to enhancing construction techniques that effectively utilize recycled materials. Addressing this research gap is vital, as it may pave the way for innovative material design solutions that support eco-friendly initiatives in the construction sector. As sustainability takes on greater significance, deepening our understanding of these interactions will be crucial for realizing their complete potential in advanced concrete applications (7).

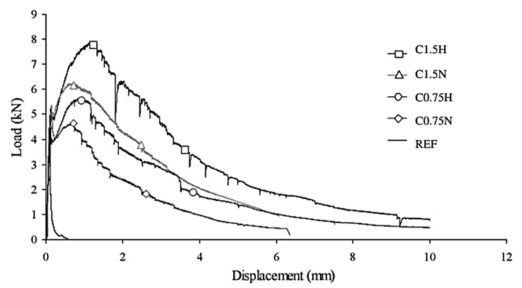
Literature Review

Use of Steel Fibers in SCC for Mechanical Properties

There is a dearth of research on using recycled steel fibers (RSF) to reinforce self-compacting concrete. However, fibers have been frequently used in SCC to improve mechanical properties and resistance to cracking. To increase the cracking resistance of self-compacting concrete, steel fibers were added to the mixture using different percentages of the total volume, were **Maidl**, (8); **Pengfe et. al.** (9); **Al-Ameeri**, (10) discovered that, similar to tensile strength, the inclusion of steel fibers little affects compressive strength. The fibers' inclusion results in an increase in ductility. **Pajak** (11) investigated the impact of hybrid fibers (steel and polypropylene) on the mechanical properties of SCC and discovered that steel fiber significantly contributes to the enhancement of mechanical properties.

In the meantime, a hybrid blend containing polypropylene fiber contributes to a minor increase in toughness. However, this concrete did not satisfy the standards of a new SCC. The impact of altering the micro steel fiber content on the characteristics of steel fiber reinforced high strength lightweight self-compacting concrete was examined by **Iqbal et al.** (12). According to this study, to determine the mechanical qualities by examining the differences between its fresh and hardened qualities, various fiber contents (0, 0.5, 0.75, 1, and 1.25%) were tested. The findings indicated that a steel fiber content of 1% or more had a significant impact on workability, while an increase in the amount of steel fiber to reach 1.25% caused a reduction in compressive strength by about 12%, while it increased the tensile and flexural strength of about (37% and 110%), respectively, without a change in modulus of elasticity. Additionally, **Okeh et al.** (13) conducted a laboratory study on two distinct steel fiber hybridization conditions using straight steel fiber (diameter 0.2 mm and length 13 mm) with two distinct kinds of hooked end steel fibers (single and double hook) at 0.75% and (1%) fiber contents, respectively. Regardless of the type of fibers, all these types decreased workability.

On the other hand, using the steel fiber with a macro-single hook (hooked from one end) improves mechanical properties such as compressive strength, tensile strength, and fracture energy. In contrast, fracture energy was observed to decrease when using the macro-double hooks (hooked from both ends). However, there were positive results concerning other properties. Experiments investigate that the major factor that influences flowability and workability is the fiber's geometry rather than its strength, as **Ackay** and **Tasdemir** (14) showed when they were used Fig (1). There was the enhancement of more ductility and energy of fracture when using the long steel fiber concrete with high strength than the steel fiber concrete with normal strength. On the other hand, concrete with high-strength and long steel fibers shows a behavior of enhanced toughness and ductility compared to that with normal-strength steel fibers.



HSSF: high-strength steel fibers. **NSSF:** normal strength steel fibers. **C1.5H:** 1.5% of HSSF. **C1.5N:** 1.5% of NSSF. **C0.75H:** 0.75% of HSSF. **C0.75N:** 0.75% of NSSF. **REF:** 0% of fibers.

Figure 1: Ackay & Tasdemir curves of load-displacement for five mixes (14).

Using scrap tires, **Khaleel et al.** (15) investigated the mechanical performance and rheological behavior of self-compacting concrete using varying lengths and amounts of RSF. This investigation referred to those long fibers improved flexural strength, while shorter fibers had a greater impact on the rheological behavior of self-compacting concrete. However, favorable outcomes are observed in terms of mechanical properties. Steel fibers have been shown in studies to reduce the mix's workability. For improved flow characteristics, it is crucial to ascertain the right percentage of steel fibers for reinforcing self-compacting concrete (16, 17, 18). Therefore, it can be noted that increasing the fiber length to a certain extent improves the properties of concrete (19).

Nanomaterials as an Additive in SCC

Nanomaterials play a crucial role in enhancing the performance and sustainability of self-compacting concrete (SCC). Their integration leads to significant changes in the properties of concrete at micro and nano scales, resulting in improved mechanical characteristics. By manipulating materials at the atomic level. The morphology and shape of the nanomaterials can be characterized by a scanning electron microscope (SEM), while their size and the shape are observed under a transmission electron microscope (TEM) (20). Nanotechnology optimizes particle packing and reduces voids within the concrete matrix, ultimately enhancing strength and durability (5, 6). The effectiveness of nanomaterials is linked to their large surface area, which facilitates better interactions with cement-based mixtures. The use of nanomaterials to improve the mechanical properties of self-compacting concrete has demonstrated impressive promise. One of the most popular nanomaterials to incorporate into concrete is nano-silica. Compressive, tensile, and flexural strengths can all be considerably increased by adding nanomaterials, according to research findings (21). Research has shown that nanoparticles are essential in promoting the formation of C-S-H gel by filling pore-structure in the nanoscale and offering sites for precipitation nucleation. This improvement can be attributed to the large surface area of nanomaterials, which serve as nuclei for hydration products and reduce pores within the concrete, improving its microstructure and lowering porosity and permeability. As a result of this, the concrete's microstructure becomes denser. Additionally, these materials exhibit pozzolanic reactivity, which supports hydration reactions (8, 22). By improving microstructural characteristics through nanoparticle filling effects and pozzolanic reactivity, glass powder additives to concrete may prove highly effective in enhancing durability and mechanical properties. The pozzolanic reaction is largely privileged when the glass powder has a diameter of less than (75 μm) (23, 24, 25, 26). Table (1) shows a summary of the major previous studies related to the influence of these materials on the properties of self-compacting concrete. From the previous studies above, it can be concluded that nanomaterials play a crucial role in facilitating pozzolanic reactions during the hydration process.

This reaction refines the concrete's microstructure and improves the compressive strength, flexural strength, and overall durability. Variations in particle size and composition can significantly affect performance outcomes. If not properly managed, this may result in clumping or uneven dispersion, hindering the expected performance improvements.

Table 1: Summary of the most previous research related to the effect of nanomaterials on the properties of SCC.

Researcher (s)	Type of Nanomaterials	Particle Size	Conclusion
Abbas et al. [16]	Nano-silica	(Colloidal)	A w/b ratio of 0.35 and a 0.9% nano-silica content increased the splitting tensile strength (STS) of self-compacting concrete by 40% compared to the reference mix.
Hamdy, et al. [27]	Nano-silica & Nano manganese ferrite	(Powder) (9.08 -19.38 nm) & (3.24 - 25.85 nm).	According to the results, adding nano silica and replacing 25% of the cement with fly ash enhanced the mechanical and durability characteristics of SCC. Additionally, reinforced concrete beams tested in bending to failure showed improved flexural performance.
Mazloom, et. al. [28]	Nano-silica	(Powder) (10-20 nm)	The findings showed that nearly every self-compacting lightweight concrete property met EFNARC standards [29] and produced improved mechanical properties. Additionally, the improvement in electrical resistivity and ultrasonic pulse velocity was superior compared to control mixes.
Maghsoudi, et. al. [30]	Nano-silica	(Colloidal)	The characteristics of SCC with and without nano-silica by looking at them under a scanning electron microscope (SEM). They suggested that the toughened qualities of SCC might be enhanced by combining the usage of nano and micro-silica.
Nazari & Riahi [31]	Nano ZrO_2	(Powder) D: (15 ± 3 nm)	Nano ZrO_2 impact on SPT by substituting cement with (NanoZrO_2 > 4%) caused a reduction in STS of self-compacting concrete owing to the inappropriate dispersion of nanomaterials, self-compacting concrete by partially replacing cement (< 4% of its weight) might increase split tensile strength and improve the rate of hydration.
Mohseni, et al [32]	Nano (SnO_2 + ZrO_2, + $CaCO_3$)	(Powder) Average diameter (20 ± 3 nm)	With higher chloride penetration, water resistance, and compressive strength, nanoparticles demonstrated improved transport capabilities. Additionally, the micropore system was improved. By weight of cement, it was discovered that the optimal ratios of nanoparticles were 3% $CaCO_3$, 4% ZrO_2, and 5% SnO_2.
Khoshakhlagh, et. al. [33]	Nano Fe_2O_3	(Powder) D: (15±2 nm)	Investigated the characteristics of high-performance SCC by incorporating nanoscale Fe_2O_3. They concluded that when adding (Fe_2O_3 > 4%) by weight of cement can enhance the SCC porosity, which will enhance the concrete's permeability as well as its compressive, split tensile, and flexural strengths after hardening.
Miyandehi, et. al. [34]	Nano Al_2O_3	(Powder) 15 nm	Nano Al_2O_3 is utilized in SCC in varying weight percentages (1%, 3%, and 5%) while maintaining a constant fly ash composition of 25%. According to their experiments, self-compacting concrete with 25% fly ash and 1% (nano Al_2O_3) partial replacement has better mechanical, strength, and durability qualities.
Puentes, et. al. [35]	Nano-silica + carbon nano-fibers	(Aqueous Suspension) D: (20–80 nm) and L:(30 lm)	While carbon nanofibers and nano-silica enhanced the flexural and compressive strengths of the hardened pastes, they also raised the probability of early-age cracking, which can reduce the durability of SCC.
Somasri & Kumar [36]	Graphene Oxide (GO)	Dissolved with Sodium Nitrate and Sulphuric Acid	Examined the mechanical and rheological characteristics of the high-strength SCC that was integrated with GO. Flexural, compressive, and tensile strength all showed increases of 28%, 17%, and 40%, respectively.
Tufail, et. al. [37]	Graphite nano (GNMPs)	Diffused GNMPs using Acacia Gum	The findings showed that using GNMPs through SEM enhanced SCC filling and passing capabilities. Additionally, a 0.3% GNMPs addition resulted in a 42% and 21.3% increase in compressive and tensile strength, respectively.
Nazari, et. al. [38]	CuO nanoparticles	(Powder) D: (15±4 nm)	At the early age of hydration, the rate of formation of crystalline $Ca(OH)_2$ increased. (Nano CuO < 3% wt.) accelerated the formation of C-S-H gels, whereas (> 3% wt.) decreased the splitting tensile strength due to a decrease in $Ca(OH)_2$. Improved mechanical and physical properties were demonstrated using X-ray diffraction.
Arefi & Zarchi [39]	ZnO nanoparticles	(Powder) 30 nm	Nano ZnO improved the flexural strength of SCC. ZnO content < 0.2% improved the flexural strength, while pore structure shifted the distributed pores to less harmful or harmless pores, causing an increase in the mechanical strength.
Langaroudi & Mohammadi [40]	nano-clay (NC)	Powder of montmorillonite clay/layer thick. (1–2 nm)	According to the results, the addition of 3 percent nano clay to the mix improved the frost and freeze-thaw resistance of self-compacting concrete with mineral admixtures.

Use of Materials (Nanomaterials and Steel Fibers from Scraps Tires)

The integration of recycled steel fibers (RSF) and nano glass into SCC represents a modern approach aimed at enhancing mechanical properties. The unique characteristics of RSF, such as their exceptional tensile strength and ability to bridge cracks, are crucial for improving the structural integrity of concrete. When paired with nanomaterials, which possess significant pozzolanic activity, the overall mechanical performance of SCC can see notable enhancement due to improved bonding within the matrix and aggregates. The properties of self-compacting concrete mixes in both their fresh and hardened phases are impacted when manufactured steel fibers are added (41, 42).

According to earlier research, the rheological properties of SCC may suffer if produced steel fibers are used in the material (42, 43). Manufactured steel fibers can reduce the density of self-compacting concrete in the fresh state, raise the likelihood of segregation, increase the viscosity (passing ability), and decrease the flowability. Nevertheless, there aren't many studies on how using RSF in SCC blends affects the fresh qualities. The tensile, flexural, shear, impact, and shrinkage strength of concrete members may be enhanced by the random distribution of discontinuous produced steel fibers of varying length and composition.

These SF can stop or slow down the propagation of cracks. Therefore, it can limit microcracks (i.e. cracks at an early stage of loading history) (41, 43). Several investigations have documented the impact of RSF on the mechanical characteristics of regular concrete (3, 44, 45, 46). According to reports, RSF can perform comparably to steel fiber manufacturers (3, 26). It can therefore be utilized as a substitute for the pricey steel fibers that are created. A summary of the most prior research on the impact of nanomaterials on the characteristics of fibrous SCC is also provided in Table (2). Based on the collected data, it can be said that studies regarding the performance and microstructure of concrete containing both fibers and nanomaterials are very scarce. Any further usage of nanomaterials tends to have a positive effect on physical, mechanical, and their structural behavior, provided that the rheological properties of fibrous self-compacting concrete are maintained. In addition to durability by reducing the porosity, because these pores draw water, which causes major negative consequences such as less resistance to chloride ions, increased acid intrusion, freezing and thawing, and abrasion resistance due to decreased compressive strength (47).

Table 2: Summary of the most previous studies related to the effect of nanomaterials on the properties of fibrous SCC

Researchers	Combined		Effect on SCC Properties
	Type of Nanomaterials	Type of Fibers	
Ansari rad et al. [48]	Silica + aluminum nanoparticles	Basalt fiber L: (6 & 12mm) and D: (13 µm)	Basalt fibers had minimal impact on increasing compressive strength and decreased the flowability of SCC.
Moghaddam et. al. [49]	Aluminum oxide nanoparticles	Glass fibers L: (10 mm) and D: (10 µm)	59% and 119.2% increase in the compressive and tensile strength of SCC, respectively, when the combined usage of (2% Al2O3 and 1% glass fiber). When nano-aluminum-oxide and glass fibers are used together, the absorption rate of water is decreased in comparison to the sample without these components, increasing the sample's resistance to unfavorable environmental conditions.
Ghanbari et. al. [50]	Nano-silica	Glass fibers L: (12 mm) and D: (0.02 mm)	The resistivity of electricity increased (136 - 194%) when glass fiber was used with nano-silica while splitting tensile strength improved by roughly (3 - 56%). The calcium hydroxide that is rapidly organized inside the hydration is consumed by nano-silica because of its high specific surface and strong reactivity. This causes the pores to fill with the C-S-H gel and ultimately produces an increasing number of compacting hydrated products.
Althoey, et. al. [51]	Nano-sesame stalk nan-sesame stalk, and nano-wheat straw ash	Basalt fiber L: (6 & 12mm) and D: (0.02 mm)	(10% NWSA) greatly enhanced SCC's mechanical characteristics. Compressive strength increased by 27.55%, splitting tensile strength increased by 17.36%, and flexural strength increased by 21.5%. In every extreme durability test, the SCC sample with 10% NWSA performed better. Because of the breakdown of ettringites and the absorbed evaporate and capillary water, XRD examination showed the formation of microcracking at temperatures of 450 and 600°C.
Yang, et. al. [52]	Nano-SiO2	Basalt fiber L: (12mm) and D: (16 µm)	Microstructure analysis revealed that the matrix of concrete became denser due to the filling action of nano-SiO_2. The crack formation in the concrete matrix was effectively inhibited by the basalt fiber. Furthermore, by adhering to the basalt fiber and encouraging the synthesis of hydrated calcium silicate from $Ca(OH)_2$(CH), nano-SiO_2 improved bonding and decreased the possibility of concrete spalling.

Conclusions

Self-compacting concrete's (SCC) performance has been greatly enhanced by the use of nanoparticles and recycled steel fibers, however, there are still many unanswered questions to fully explore their potential. Most current research focuses on recycled fibers or nanomaterials, with little investigation into how these two elements work together to affect the mechanical properties and durability of SCC. Furthermore, more research is needed to determine how well SCC performs over the long run using these materials in different environmental settings.

The literature analysis and conversations allow for the conclusions that follow to be made:

1- The unique characteristics of RSF, such as their exceptional tensile strength and ability to bridge cracks, are crucial for improving the structural integrity of SCC. When paired with nano glass, which possesses significant pozzolanic activity, the overall mechanical performance of SCC can see notable enhancement due to improved bonding within the matrix and aggregates.
2- When nanomaterials are used with fibers in concrete, it takes more energy to debond the fiber from cement paste, resulting in a higher flexural capacity.

The following issues are highlighted for further research:

1- Suggest that adding nano-glass to steel fibers may improve their mechanical qualities, lower their porosity, stop cracks from spreading, and increase their durability.
2- Future research should determine the economic feasibility of producing nano-glass and the processing of recycled steel fibers for broader concrete applications. Also, assessing cost factors related to their integration into conventional construction practices.
3- It is critical for worker safety to look into the health risks related to handling nanomaterials during production.
4- The pozzolanic reaction resulting from the nano glass reaction was not used to improve the properties of SCC.

Because of the pozzolanic interaction of glass due to the increase in surface area, the review suggests using nano glass as a partial replacement for cement as long as the self-compacting concrete satisfies the EFNARC (29) requirements to benefit from the silica found in the glass composition, which is expected to increase the hydration products and reduce the porosity. Thus, it will enhance the bond strength between steel fibers and cement paste, making SCC more ductile and enhancing its structural behavior, which will assist in reducing the likelihood of brittle failure.

Ethics approval and consent to participate

The authors confirm that they respect the publication's ethics and consent to their work's publication.

Consent for publication

The authors consent to the publication of this work.

Author's contribution

The authors confirm their contributions to the paper as follows:

The main idea and its novelty: Sheelan M. Hama.
Study design and conception: Mohammed T. Nawar and Sheelan M. Hama.
Analyzing and interpreting the results based on previous studies: Mohammed T. Nawar.
Preparing the manuscript: Mohammed T. Nawar and Sheelan M. Hama.

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Conflicts of interest

The authors declare that there is no conflict of interest regarding the publication of this article.

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