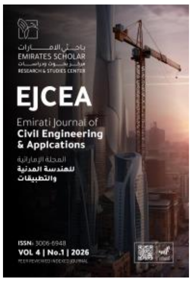

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Innovating for a Greener Future: Steel Fiber Reinforcement as a Key to Low-Carbon Concrete Construction

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ABSTRACT

The construction industry in GCC experiences continuous challenges in achieving sustainability targets toward net zero emissions by 2030 in alignment with the universal sustainable development goals. Concrete structures specifically contribute to most upfront carbon dioxide emissions that resulted from the clinker production of ordinary cement which generates high amounts of carbon emissions and uses high rates of energy which is against the sustainable development initiatives to lower the energy consumption in GCC. Having concrete is weak in resisting tensile stresses, most concrete applications are reinforced with steel mesh, and the steel reinforcement has high environmental product declared values as the process of production is energy intensive. Steel fiber concrete is strongly introduced as a sustainable solution and alternative to the steel reinforcement in concrete. Its high ability to heal and control the cracks in concrete by enhancing the ductility of concrete. Considering its lower declared values of carbon emissions compared to the normal steel mesh, the steel fiber has positioned itself as a promising solution to decarbonize different applications such as residential slab on grades. Additionally, the hybrid effect of adding steel fiber with steel reinforcement as combined increases the tensile resistance of concrete lowering the required amount of basic steel reinforcement to control crack widths. Steel fiber also improves the shear resistance of concrete which significantly reduces the element thickness under high concentrations of loads giving more alternative to architectural intents, cutting cost of materials and lowering the upfront carbon emissions. This paper investigates the environmental impacts of using steel fiber in residential slab on grades presenting a case study of project (Expo the Valley) in UAE where the steel fiber Dramix® had been utilized to optimize the thickness of slab on grades and replaced the steel mesh saving significant levels of carbon dioxide emissions. The findings clearly demonstrate that steel fiber can significantly lower carbon dioxide emissions considering its effects in design optimization and its low Environmental Product Declared Values.

Keywords: *Steel Fiber Reinforced Concrete (SFRC), Embodied Carbon, Sustainable Construction, Environmental Product Declaration, Structural Optimization, High Ductile Concrete, Crack Control* https://doi.org/10.54878/1959z822

Introduction:

The construction industry is responsible for most of the carbon dioxide emissions globally. The continuous development of buildings and other structures increases the pressure on the local governments to adopt new strategies of using sustainable materials as alternatives for concrete to lower the upfront carbon dioxide emissions as the majority of structures are built using concrete and concrete production produces the highest rates of carbon emissions from the fuel consumption during the clinker generation process which is the core process of cement production. Additionally, considering the low tensile strength of concrete , reinforcement is used to resist the tensile and bending forces in the majority of structural and non-structural concrete applications. However, the production of steel reinforcement requires high levels of energy and produces significant amounts of carbon dioxide emissions. Applications like residential slab on grades, where concrete is under compression and cracking control because of shrinkage and thermal changes, the steel fiber presented a powerful optimized alternative to steel mesh which proves significant saving in material quantities and lower carbon emissions as well. The capability of steel fiber to bridge the cracks in concrete enhancing its ductility and tensile strength, makes it the best solution to offer optimized and sustainable design of slab on grades. In this paper, a case study of residential project

(Expo the valley) is presented where Dramix® steel fiber is used to replace fully the steel mesh reinforcing the villas slab on grades cutting down the carbon emissions by 80-90% considering the reduced concrete volume and, relative percentage of steel provided in concrete volume and the relative value of carbon emissions produced for each 1kg of the material.

2. Literature Review

2.1 Development of Steel Fiber Reinforced Concrete

Steel fiber reinforced concrete (SFRC) has been first introduced to construction industry in early 1970s. The initial investigations studied in the fib model code recognize the ability of steel fiber to bridge the cracks after concrete reaches its rupture strength under the effect of moment redistribution allowing the cracking behavior to be restrained in minor light cracks that are intensive but controlled. At first, steel fiber was used mainly to control cracks with its anchorage effect to replace steel

reinforcement by increasing the concrete element load bearing capacity.

This finding had been further developed in the guide of design for steel fiber concrete ACI544 provided that the performance is measured by the amount of post cracking (residual) strength to be provided after concrete is cracked. The ACI544 demonstrated the approach to link experimental beam testing results to performance classes where steel fibre provide ductility to concrete depending on the quality of the steel fibres in terms of length , tensile strength, aspect ratio and anchorage performance.

2.2 Structural Design Frameworks

The design of steel fiber reinforced concrete structures are well presented in several international design standards and codes.

The ACI 544 provides several documents as guidance in design, mixing, and dosing of the steel fiber in concrete elements. ACI544-18.3R forms the fundamental basis of design for steel fiber concrete applications which rely on the performance evaluation as per the international bema test according to ASTM

C1609 and the acceptance criteria provided the residual strength values which are the main parameters affecting the bending, shear and punching shear capacity provided by steel fiber to concrete.

The same methodology of performance-based design is well detailed in Annex-L of the Eurocode-2 EN 1992 which acknowledges the use of steel fiber as replacement for the steel reinforcement partially or fully depending on the type of structures.

2.3 Mechanical Benefits of Steel Fibers

Steel fibers improve several key mechanical properties of concrete:

- Tensile strength
- Flexural strength
- Ductility
- Impact resistance
- Crack control
- Post-cracking load carrying capacity

The primary mechanism behind these improvements is the fiber bridging effect, illustrated conceptually below.

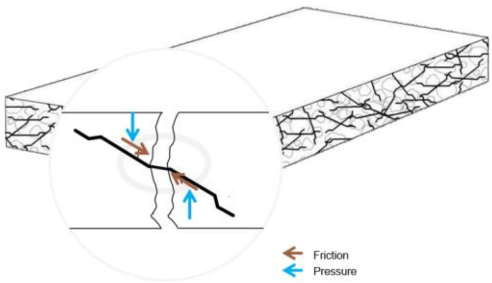

Figure 1 - Crack Bridging Mechanism of Steel Fibers

Steel fiber acts as bridge under the effect of anchorage in concrete allowing the tensile forces to transfer through its ends sustaining the concrete ductility and avoiding sudden failure.

3. Purpose and Objectives of the Study

The main objective of this paper is to evaluate the potential of steel fiber reinforcement to reduce embodied carbon in concrete construction while

maintaining structural performance and integrity.

The specific objectives include:

1. Investigating the structural benefits of steel fiber reinforcement.

2. Evaluating the environmental impact of steel fibers compared to traditional reinforcement.

3. Demonstrating the practical application of steel fibers in residential slab-on-grade construction.

4. Methodology / Research Approach

The research methodology includes three primary components:

1. Literature Review

Review of international design standards and research publications related to fiber reinforced concrete.

2. Embodied Carbon Assessment

Comparison of embodied carbon between conventional reinforcement systems and steel fiber reinforcement using Environmental Product Declaration (EPD) data.

3. Case Study Analysis

Evaluation of a residential slab-on-grade system in the Expo City "The Valley" townhouse development in Dubai where steel fibers from Ms. Bekaert were considered as part of the structural solution.

5. Findings / Results

5.1 Structural Performance Steel fibers significantly enhance the post-cracking behavior of concrete. Residual tensile strength enables the concrete to maintain load-carrying capacity after cracking, improving structural ductility and enhanced the concrete ability to heal cracks while not compromising with structural integrity.

5.2 Carbon Comparison

A comparative embodied carbon assessment was conducted between conventional reinforcement and steel fiber reinforcement.

Table 1 - Embodied Carbon Comparison

Material	Typical Dosage	Embodied Carbon (kg CO_2/kg)	Carbon Impact per m³
Rebar Steel	35 kg/m³	1.7	59.5 kg CO_2
Steel Fibers	10 kg/m³	0.6	6 kg CO_2

Estimated Carbon Reduction: is 90% reduction in reinforcement-related carbon dioxide emissions.

This comparison clearly demonstrates the advantage of steel fiber in improving the environmental aspects by lowering the percentage of carbon dioxide emissions.

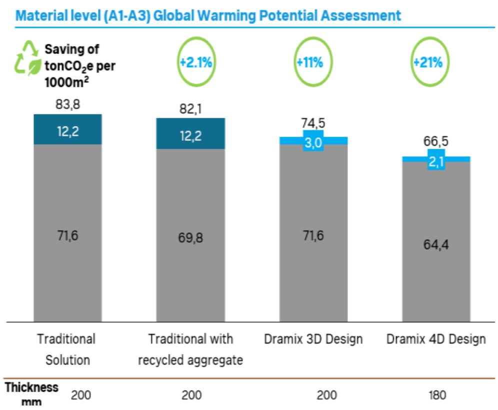

Figure 2 - Carbon Reduction Potential

Comparison of the Carbon emissions in concrete mix reinforced with traditional mesh compared to steel fiber concrete mix reinforced with Dramix® steel fiber 3D and 4D.

6. Case Study: Residential Slab-on-Grade - Expo City "The Valley"

Project Overview

The Valley is a large residential development consisting of low-rise townhouse communities located in Expo City Dubai.

Conventional Design

Typical slab design:

- Concrete strength: C30/37
- Thickness: 150mm with edge thickening of 200mm
- Reinforcement: BRC normal mesh

Steel Fiber Alternative

Steel fiber reinforced concrete was proposed as an alternative reinforcement system.

Typical mix:

- Concrete strength: C30/37
- Steel fiber dosage: 10 kg/m³ Dramix® 4D 8060BGE
- Thickness: 100mm without thickening edge.

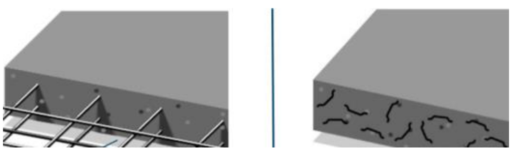

Figure 3 - Conventional vs Steel Fiber Slab

Observed Advantages

1. Elimination of reinforcement mesh installation.
2. Faster construction time.

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3. Reduced labor requirements.
4. Lower reinforcement carbon footprint.
5. Improved crack control.

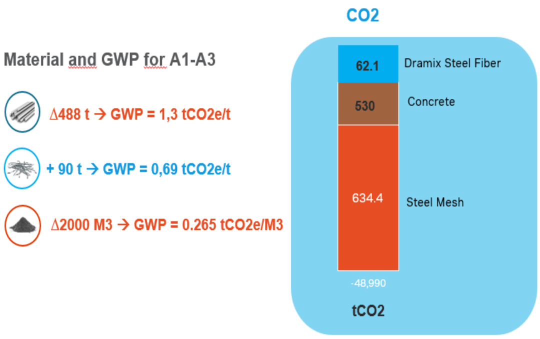

Figure 4 - Conventional vs Steel Fiber Slab Life Cycle Assement. Material and GWP for A1-A3

7. Discussion

The results demonstrate that steel fiber reinforcement can significantly reduce or replace fully the steel reinforcement quantities while improving structural performance, integrity and ductility of concrete. The carbon comparison indicates that replacing conventional reinforcement with steel fibers can reduce reinforcement-related emissions up to 80-90%.

Furthermore, the simplified construction process associated with steel fiber concrete reduces the labour and construction time, contributing to additional sustainability benefits comparing to the steel works which requires higher volume of manpower for fixing , handling and installation. Steel fiber mixing and dosing are simple processes which don't require high volume of workmanship.

8. Conclusion, Implications and Recommendations

Steel fiber in concrete represents a promising technology to replace the steel reinforcement which as in impact lowers the carbon dioxide emissions while providing concrete ductility , toughness and integrity.

The study in this paper leads to the following **results :**

1. The tensile strength of concrete is improved by adding steel fiber.
2. Adding steel fiber to concrete enables optimization in design by reducing the concrete volume needed and replaces the steel mesh with less percentage of reinforcement but in 3D directional reinforcing the concrete and enhancing the ductility, toughness while lowering the amount of carbon dioxide emissions.
3. The steel fiber when added to concrete as replacement for steel mesh reinforcement lowers then total upfront carbon emissions makes it a promising solution for sustainable concrete and healthier for the environment.
4. The practical simplified process of mixing and dosing of steel fiber in concrete demonstrates a promising solution for residential slab on grades.

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