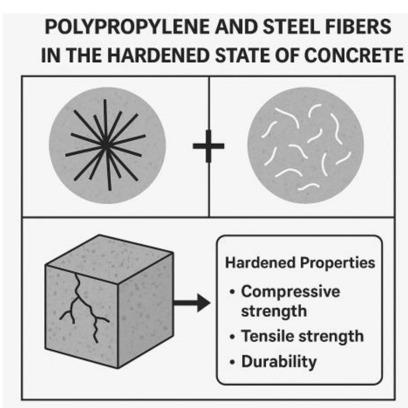
To understand the effect of incorporation of polypropylene and steel fibers together in the hardened state of concrete

Amar M.Chipade[1], Aiman[2], Abhinav Sharma[3]
[1] pdf, Lincoln University College, Malaysia ; [2] Supervior, Lincoln University College, Malaysia; [3] Cosupervisor, Lincoln University College, Malaysia
pdf.amar@lincoln.edu.my

Abstract:

This study investigates the combined effect of polypropylene (PP) and steel fibers on the hardened properties of concrete. Fiber-reinforced concrete has emerged as a promising material for enhancing the mechanical and durability characteristics of conventional concrete. While individual use of polypropylene and steel fibers has shown significant improvements in specific performance parameters, this research aims to evaluate the synergistic impact when both fibers are incorporated simultaneously. Concrete mixes were prepared with varying proportions of PP and steel fibers, and tested for key hardened state properties, including compressive strength, split tensile strength, flexural strength, and durability aspects such as water absorption and resistance to cracking. The experimental results highlight that the hybrid fiber combination offers enhanced performance due to the complementary nature of the fibers—where steel fibers contribute to strength and crack-bridging capacity, and polypropylene fibers improve ductility and shrinkage resistance. This research provides insights into optimizing fiber content for achieving superior hardened concrete performance, thereby supporting the development of more durable and resilient construction materials.

Graphical Abstract:



Keywords: Fiber-reinforced concrete (FRC); Sustainability; Compressive Strength, Tensile Strength

Introduction

Sustainability in the construction industry has become a key focus due to the increasing demand for durable, resilient, and environmentally friendly building materials. Among various advancements, fiber-reinforced concrete (FRC) has gained significant attention for its ability to enhance the mechanical and durability properties of conventional concrete. The incorporation of fibers, such as steel, synthetic, glass, or natural fibers, improves properties like tensile strength, impact resistance, ductility, and crack control, thereby extending the lifespan of structures.This review explores the role of fiber reinforcement in enhancing the sustainability of concrete structures by assessing its mechanical performance (e.g., compressive, tensile, and flexural strength) and durability aspects (e.g., resistance to corrosion, freeze-thaw cycles, and chemical attacks). By integrating fiber-reinforced concrete into modern construction, engineers and researchers aim to reduce maintenance costs, minimize material wastage, and contribute to sustainable infrastructure development. Through a comprehensive analysis of recent studies, this paper highlights the potential of fiber-reinforced concrete in addressing structural sustainability challenges and provides insights into its practical applications in civil engineering.

Types of Fibres Used in Concrete

Fibers used in concrete can be classified into various categories, including:

- **Steel fibers**: Improve tensile strength, impact resistance, and ductility.
- **Synthetic fibers (polypropylene, nylon, polyester, etc.)**: Enhance shrinkage crack control and flexibility.
- **Glass fibers**: Increase resistance to alkali attack and improve tensile properties.
- **Natural fibers (coir, jute, sisal, etc.)**: Provide an eco-friendly alternative, improving ductility and crack resistance.
- **Carbon fibers**: Enhance flexural strength and conductivity for smart concrete applications.

Functions of Fibre in Concrete

Crack Control and Toughness Enhancement

Fibers help control cracking due to shrinkage, thermal changes, and mechanical stress. They bridge cracks and distribute stress more evenly, enhancing toughness.

Improved Tensile and Flexural Strength

The addition of fibers enhances the tensile and flexural properties of concrete, making it more resilient under load and reducing brittleness.

Impact and Fatigue Resistance

Fiber-reinforced concrete (FRC) demonstrates higher resistance to impact and cyclic loading, making it suitable for heavy-duty applications such as pavements and industrial floors.

Durability and Permeability Reduction

Fibers reduce permeability by minimizing microcracks, thus improving resistance to water ingress, chemical attacks, and freeze-thaw cycles.

Fire Resistance

Certain synthetic fibers (e.g., polypropylene) enhance fire resistance by melting at high temperatures, creating microchannels that release steam and prevent explosive spalling.

Improved Post-Cracking Behavior

Unlike conventional concrete, fiber-reinforced concrete retains load-bearing capacity even after initial cracking, preventing sudden failure.

Mechanical Properties of Fibre-Reinforced Concrete

Compressive Strength.
Fibres slightly enhance compressive strength by improving stress distribution and crack resistance.
Tensile Strength
FRC exhibits higher tensile strength due to crack bridging mechanisms of fibres, improving ductility and fracture resistance.
Flexural Strength

Flexural strength improves significantly with fibre addition, enhancing load-carrying capacity and reducing failure risks.

Applications of Fibre-Reinforced Concrete

Fiber-reinforced concrete is widely used in applications such as:

- Industrial floors and pavements
- Bridge decks and overlays
- Tunnel linings and shotcrete applications

- Precast concrete elements
- Marine structures and hydraulic constructions

Composite action of fibre and concrete

The composite action of fibres and concrete significantly enhances structural performance, durability, and sustainability. While challenges exist, advancements in fibre technology and optimized mix designs can further improve FRC applications. Future research should focus on sustainable fibre alternatives and hybrid fibre systems to maximize benefits.

Need of Study

Traditional concrete often cracks and has lower durability over time. Fiber-reinforced concrete (FRC) is stronger, resists cracking, and lasts longer. This study helps understand how FRC can solve these problems and make structures more durable. With limited resources and rising environmental concerns, sustainable materials are needed in construction. FRC increases structure lifespan, reduces repairs, and uses eco-friendly fibers like recycled or natural ones. This study shows how FRC helps in sustainable construction.

Literature Survey

Mechanical properties and durability of steel fiber reinforced concrete: A review (Yuanxun Zheng a b, Xiaoman Lv a b, Shaowei Hu a, Jingbo Zhuo a b, Cong Wan a b, Jiaqi Liu c) Journal of Building Engineering Volume 82, 1 April 2024, 108025 It can be seen that SF can enhance the interface structure, mechanical properties, and fracture properties of SFRC, and thus improve the durability of concrete.[1]

Enhancing the mechanical properties of fibre-reinforced concrete through sustainable mix design: effects of fiber type and dose (Sabahat Ahmad Khan1) Material building and Design 2023 This study demonstrated that integrating various types of fibers and recycled materials into M20 grade concrete can significantly enhance its mechanical properties while promoting sustainability.[2]

Enhancing durability and sustainability in concrete with fibre-reinforced composites Abdelatif Salmi Journal Of Water And Land Development e-ISSN 2083-4535 . This study has presented a comprehensive exploration of the transformative potential of self-healing mechanisms and sustainable material integration in fibre-reinforced concrete (FRC) production. [3]

Fiber Reinforced Concrete: A Review Muhammad Anas *, Majid Khan * , Hazrat Bilal, Shantul Jadoon and Muhammad Nadeem Khan Engineering Process ding . This paper intended to present the effects of adding various types of fibers in concrete. [4]

Sustainable Concrete-Based Structures: Review for the Potential Benefits of Basalt Fiber Reinforced Concrete (BFRC) in Enhancing the Environmental Performance of Buildings. Nadine Albqour, Mohammad Shehata, Zeyad Elsayad, Shaher Rababeh This paper indicated the related studies that explored and investigated the features of BFRC in the field of construction buildings, that particularly found encouraging results. However, most of the related research focused on mechanical properties and structural performance, while Studies focusing on thermal properties and environmental performance have been modest and still sketchy.[5]

The Improvement of Durability of Reinforced Concretes for Sustainable Structures: A Review on Different Approaches . In particular, it is shown how it is possible to realize durable reinforced concrete structures in different aggressive environments through an appropriate design that starts from a proper concrete composition.[6]

A comprehensive study on enhancing of the mechanical properties of steel fiber-reinforced concrete through nano-silica integration. **AnbuchezianAshokan1 , Silambarasan Rajendran2** & Ratchagaraja Dhairiyasamy3. Incorporating steel microfbers at higher volume fractions of 1–2% enhanced concrete’s compressive strength, tensile strength, fexural strength, and fracture energy. However, excessive fber content above 2% led to reduced workability .[7]

Optimization of Mechanical Properties and Durability of Steel Fiber-Reinforced Concrete by Nano CaCO3 and Nano TiC to Improve Material Sustainability. Yajing Wen Zhengjun Wan **Xilin Yuan and Xin Yang** It was determined after testing that NC and NT can improve the mechanical properties and durability of SFRC. Optimizing the durability properties of SFRC allows for a reasonable reduction in the size of SFRC numbers or the thickness of the protective layer at the time of design, saving material costs while ensuring structural safety.[8]

Alhozaimy, A. M., et al. This study analyzed the effect of polypropylene fibers in high-strength concrete. Results indicated a significant reduction in plastic shrinkage cracking but minimal improvement in compressive strength. The paper sets a foundation for understanding polypropylene’s role when combined with other fibers like steel.

Banthia, N., & Gupta, R. Researchers evaluated hybrid fiber-reinforced concrete with steel and polypropylene fibers. They found improved crack resistance, post-crack strength, and energy absorption, confirming a synergistic effect when combining both fiber types.

Afroughsabet, V., et al. This paper examined the mechanical performance of hybrid fiber-reinforced concrete using steel and polypropylene. The study highlighted that the combination enhances toughness, flexural strength, and ductility, more effectively than single-fiber additions.

Kim, D. J., et al. This research focused on hybrid effects in ultra-high-performance concrete. A notable enhancement in tensile properties and crack resistance was observed when steel and polymer fibers were used together, proving their complementary roles.

Sonebi, M., & Grünewald, S. This experimental investigation on self-compacting fiber-reinforced concrete (SCFRC) showed that the combined use of steel and polypropylene fibers maintained flowability while improving hardened-state properties, particularly splitting tensile strength.

Ramezanianpour, A. A., et al. The study explored fiber synergy in concrete under flexural loading. It revealed that steel fibers contributed to load-bearing capacity while polypropylene enhanced crack control. Together, they yielded balanced mechanical performance and ductility.

Barros, J. A. O., et al. This paper presents an analytical and experimental study of hybrid fiber reinforcement in beams. It was concluded that steel fibers significantly improved flexural capacity, while polypropylene delayed micro-crack formation, enhancing fatigue performance.

Bencardino, F., et al. Their research quantified compressive and flexural behavior in fiber-reinforced concrete with different steel-polypropylene ratios. The findings emphasized that optimized fiber volume fractions provide a significant improvement in residual strength and post-peak performance.

Sadrmomtazi, A., et al. Focusing on durability aspects, this study demonstrated that hybrid fibers reduced water permeability and increased resistance to chloride penetration. Steel fibers increased strength while polypropylene enhanced resistance to environmental degradation.

Chanh, N. V. This work highlighted that the integration of steel and polypropylene fibers in concrete reduces brittleness and improves energy absorption. The results indicated better spalling resistance under fire conditions, supporting hybrid use in high-performance structures.

Literature Survey Summary

Fiber-reinforced concrete (FRC) has emerged as a promising material for enhancing structural sustainability due to its improved mechanical properties and durability. A review of the literature highlights that incorporating fibers such as steel, glass, synthetic, and natural fibers enhances compressive, tensile, and flexural strength while reducing brittleness and crack propagation. Studies have shown that FRC exhibits superior resistance to fatigue, impact, and shrinkage-related cracking, contributing to longer service life and reduced maintenance costs. Additionally, durability improvements, including resistance to freeze-thaw cycles, chloride penetration, and chemical attacks, make FRC a viable solution for sustainable infrastructure. Research also emphasizes the role of fiber type, dosage, and distribution in optimizing performance while considering environmental impacts. Overall, FRC stands as a key innovation in sustainable construction, offering enhanced strength, longevity, and resilience to structural systems.

Objective of the study

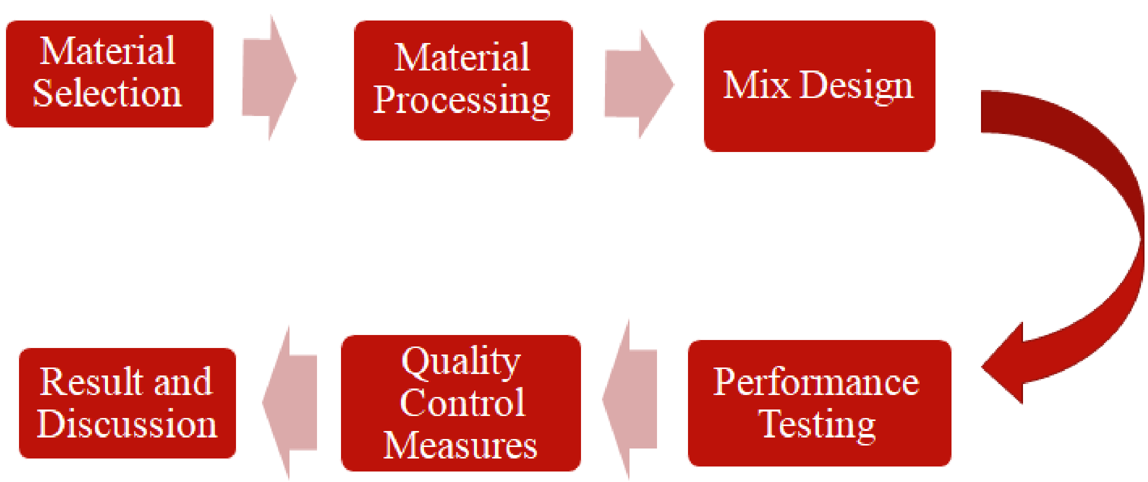
- To analyze the mechanical properties of fiber-reinforced concrete (FRC).

- ➢ To review the durability properties of fiber-reinforced concrete.

Scope of the project

- ➢ A elite cement with an objective compressive quality of 30 MPa is accomplished to be utilized in high Rise building.
- ➢ The mechanical properties, for example, pressure, Spilt Tensile, Flexural and Elastic modulus will be resolved.
- ➢ The flexural behavior of superior concrete with fibres and customary steel support will be examined.
- ➢ The solidness property, for example, water entrance test and Rapid chloride infiltration test will be considered.

Experimental Methodology



Mix Design

Basic Assumptions:

- **Cement: OPC 43 Grade**
- **Water-Cement Ratio (w/c): 0.45 (as per durability requirement)**
- **Maximum Aggregate Size: 20 mm**
- **Workability: 75–100 mm slump**
- **Type of Mix: Machine mixed**
- **Admixture: Superplasticizer (optional, for better workability)**

Target Mean Strength (f'ck):

f'ck = fck + 1.65 × S

Assuming S (standard deviation) = 5.0 MPa (as per IS 10262 for M30)

→ f'ck = 30 + 1.65 × 5 = 38.25 MPa

Mix Proportion (By Weight):

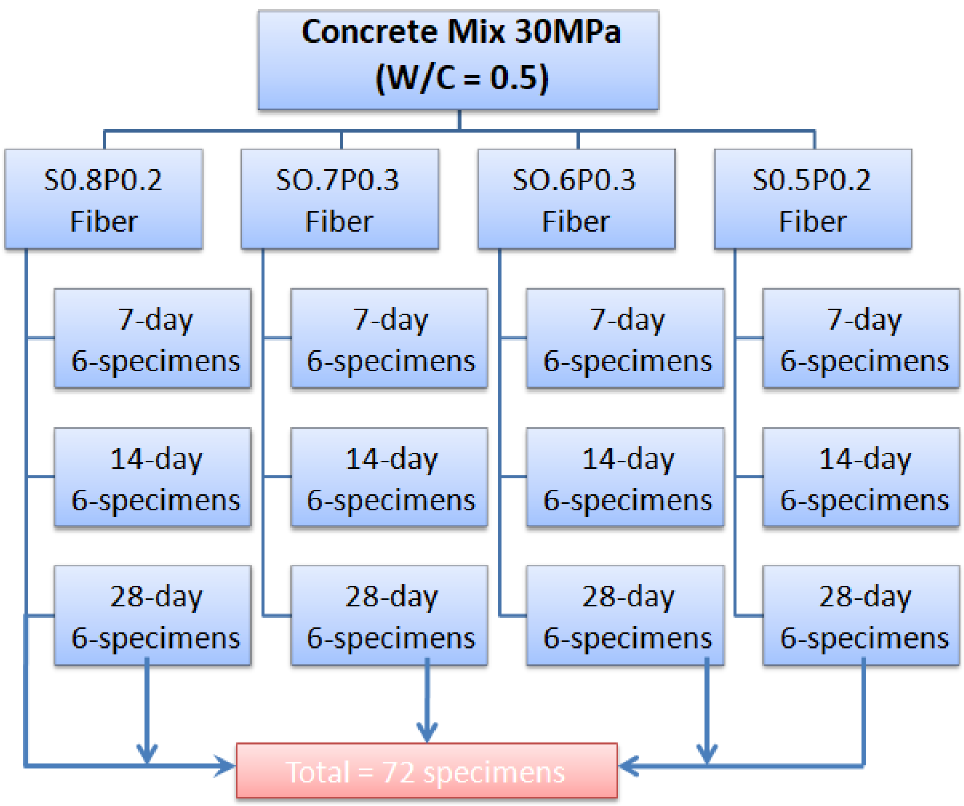
(Trial mix without admixture, for general condition)

Material	Quantity per m³ of Concrete
Cement	394 kg
Water	177.3 liters (w/c = 0.45)
Fine Aggregate	682 kg
Coarse Aggregate	1191 kg (60% 20mm + 40% 10mm)
Admixture (if used)	As per manufacturer (approx. 0.8–1% by weight of cement)

Mix Ratio (Approx by weight):

1 : 1.73 : 3.02 (Cement : Fine Aggregate : Coarse Aggregate)

Flow Chart of the Experimental Program



Properties of Fibers :

Specification	Polypropylene	Steel
Specific gravity	0.91	7.85
Tensile strength	0.67 kN/mm^2	1.1 kN/mm^2
Young's Modulus	4.0 kN/mm^2	29 kN/mm^2
Melting point	>165°C	>=1450°C
Absorption	NIL	NIL
Fiber cut length	20mm	30mm
Diameter	-	0.6mm
Aspect Ratio	-	50

Polypropylene Fiber (PPF) in Concrete:

Advantages:

- Excellent for plastic shrinkage crack control
- Improves impact resistance and abrasion resistance
- Lightweight and easy to mix
- Does not corrode (advantage in marine or chemical environments)
- Enhances fire resistance by creating pressure relief channels (reducing spalling)

Limitations:

- Low modulus of elasticity (less effective in load transfer compared to steel)
- Not suitable for high-strength or load-bearing structural enhancements

Can affect workability at higher dosages

Steel Fiber in Concrete:

Advantages:

- Improves tensile, flexural, and shear strength
- Significantly increases ductility and toughness

- Enhances crack resistance and load-carrying capacity post-crack
- Ideal for structural applications (e.g., beams, slabs)
- Increases impact resistance

Limitations:

- Corrosion potential in harsh environments (unless stainless or coated)
- Increased concrete weight
- Reduced workability if not well distributed
- More expensive than traditional reinforcement

MIXING OF POLYPROPYLENE AND STEEL FIBRES REINFORCED CONCRETE:

The sequence for casting is as follows for FRC:

- 50 % quantity of coarse aggregates
- PPF or SF or Both the fibres in 20% quantity
- Remaining 50% coarse aggregates
- Another PPF or SF or Both fibres in 20% quantity
- 50% quantity of sand
- Another PPF or SF or Both fibres in 20% quantity
- Remaining 50% quantity of sand
- Another PPF or SF or Both fibres in 20% quantity
- Cement
- Remaining 20% of PPF or SF or Both fibres
- Water

Cube Casting




Mechanism Of Failure Of Concrete Cylinders
Under Spilt Tensile Testing and Compressive strength Testing

Result :

TENSILE STRENGTH

Only Steel fibers	• Increase by 50-140%
Only PP fibers	• Increase by 5-50%
Both steel and PP fibers	• Increase by 60-200%

IMPACT STRENGTH

Only Steel fibers	• Increase by 25-150%
Only PP fibers	• Increase by 50-100%
Both steel and PP fibers	• Increase by 125-200%

SHEAR STRENGTH

Only Steel fibers	• Increase by 150-200%
Only PP fibers	• Increase by 22-125%
Both steel and PP fibers	• Increase by 25-220%

COST ANALYSIS

Type of fiber	Percentage	Weight Per Cum of concrete (Kg)	Cost per kg(Rs)	Cost per Cum of concrete(Rs)
PPF (0.5%)	0.005	4.2	150	630
PPF (1.0%)	0.01	8.5	150	1275
PPF (1.5%)	0.015	12.73	150	1909
SF (0.6%)	0.006	44.62	50	2231
SF (1.2%)	0.012	89.37	50	4468.5

CONCLUSION

- The total energy absorbed in fiber as measured by the area under the load-deflection curve is at least 10 to 40 times higher for fiber-reinforced concrete than that of plain concrete.
- Addition of fiber to conventionally reinforced beams increased the fatigue life and decreased the crack width under fatigue loading.
- At elevated temperature SFRC have more strength both in compression and tension.
- Cost savings of 10% - 30% over conventional concrete flooring systems.

References

1. Yuanxun Zheng a b, Xiaoman Lv a b, Shaowei Hu a, Jingbo Zhuo a b, Cong Wan a b, Jiaqi Liu c Mechanical properties and durability of steel fiber reinforced concrete: A review Journal of Building Engineering Volume 82 , 1 April 2024, 108025
2. Sabahat Ahmad Khan1Enhancing the mechanical properties of fbre-reinforced concrete through sustainable mix design: efects of fbre type and dose Discover Civil Engineering.
3. Abdelatif Salmi Enhancing durability and sustainability in concrete with fibre-reinforced composites JOURNAL OF WATER AND LAND DEVELOPMENT DOI: 10.24425/jwld.2024.150258 2024, No. 61 (IV–VI): 48–54
4. Muhammad Anas *, Majid Khan * , Hazrat Bilal, Shantul Jadoon and Muhammad Nadeem Khan Fiber Reinforced Concrete: A Review †Eng. Proc. 2022, 22, 3. https://doi.org/10.3390/engproc2022022003
5. Nadine Albqour, Mohammad Shehata, Zeyad Elsayad, Shaher Rababeh .Sustainable Concrete-Based Structures: Review for the Potential Benefits of Basalt Fiber Reinforced Concrete (BFRC) in Enhancing the Environmental Performance of Buildings. REAL CORP 2024: Keep On Planning For The Real World
6. Luigi Coppola 1, Silvia Beretta 2, Maria Chiara Bignozzi .The Improvement of Durability of Reinforced Concretes for Sustainable Structures: A Review on Different Approaches . Materials 2022
7. AnbuchezianAshokan1 , Silambarasan Rajendran2 & Ratchagaraja Dhairiyasamy3 A comprehensive study on enhancing of the mechanical properties of steel fiber-reinforced concrete through nano-silica integration. Scientifc Reports | (2023) 13:20092
8. Yajing Wen Zhengjun Wan Xilin Yuan and Xin Yang .Optimization of Mechanical Properties and Durability of Steel Fiber-Reinforced Concrete by Nano CaCO3 and Nano TiC to Improve Material Sustainability. Sustainability 2025, 17(2), 641; https://doi.org/10.3390/su17020641
9. A. Ramezanianpour and P. RashidDadash, "Polypropylene – Steel Fiber Reinforced Concrete," *Cement & Environment Engineering Journal*, vol. 44, no. 2, pp. 75–83, Feb. 2012. arXiv+15ceej.aut.ac.ir+15MDPI+15
10. F. Köksal, O. Gencel, B. Unal, and M. Y. Durgun, "Durability properties of concrete reinforced with steel-polypropylene hybrid fibers," *Science and Engineering of Composite Materials*, vol. 19, no. 2, Mar. 2012. De Gruyter Brill
11. M. Ranjitham, S. K. Deepika Sree, and M. B. Danyaa, "Investigation of Hybrid Concrete Using Steel and Polypropylene Fibres," in *Advances in Materials Research (ICAMR 2019)*, G. Kumaresan et al., Eds. Singapore: Springer, Feb. 2021, pp. 89–96. SpringerLink
12. M. Brijbhushan, V. B. Karikatti, and B. Gudadappanavar, "Mechanical Properties of Steel and Polypropylene Fiber Reinforced Alkali-Activated Cement," *Journal of Propulsion Technology*, vol. 44, no. 6, 2023. Propulsion Tech Journal
13. X. Chi et al., "Experimental and Numerical Analysis of Steel-Polypropylene Hybrid Fibre Reinforced Concrete Deep Beams," *Polymers*, vol. 15, no. 10, 2023. MDPI
14. "A Review of Steel-Polypropylene Hybrid Fiber Reinforced Concrete," *Applied Mechanics and Materials*, vol. 238, pp. 26–32, Nov. 2012. Scientific.Net

15. T. Zhang and D. Pan, “Mechanical properties of steel-polypropylene hybrid fiber reinforced concrete in building structure,” *Civil Engineering Journal*, 2021. ojs.cvut.cz
16. P. C. Qian and P. Stroeven, “Development of hybrid polypropylene–steel fiber reinforced concrete,” *Cement and Concrete Research*, vol. 30, pp. 63–90, 2000. (Referenced in overview) ceej.aut.ac.ir
17. P. Sukontasukkul, “Toughness Evaluation of Steel and Polypropylene Fibre Reinforced Concrete Beams under Bending,” *Thammasat International Journal of Science and Technology*, vol. 9, no. 3, 2005. ceej.aut.ac.ir
18. N. Banthia et al., “Mechanical properties of hybrid fiber-reinforced concrete at low fiber volume fraction,” *Construction and Building Materials*, vol. 21, pp. 1088–1097, 2007. ceej.aut.ac.ir