Finite Elements Analysis of Dual Fibre Reinforced Concrete Beam Using Abaqus

Mr.S. Neethimannan[1], Dr.S. Sundari[2]
[1] PG Student, Structural Engineering, Government College of Engineering, Salem
[2] Associate Professor, Deportment of Civil Engineering, Government College of Engineering, Salem

Abstract—**This study presents finite element analysis of dual fibre reinforced concrete (DFRC) beams using abaqus software. The Concrete Damage Plasticity (CDP) model was employed to simulate nonlinear behaviour of three point bending. Four beams configurations-plain reinforced concrete beam, steel fibre reinforced concrete (SFRC) beam, polypropylene fibre reinforced concrete (PPFRC) beam, and dual fibre reinforced concrete (DFRC) beam-were analysed. Results showed that DFRC beams achieved the highest performance with 38% increase in ultimate load and 67% greater deflection compared to plain reinforced concrete. Steel fibres enhanced flexural strength and post-cracking resistance, while polypropylene fibres improved crack control and ductility. The synergistic combination of both fibre types provided superior load-carrying capacity, energy absorption, and delayed failure. Numerical results validated well with published experimental data, demonstrating the CDP model's effectiveness for simulating DFRC structures.**

Index Terms—**Abaqus, Concrete Damage Plasticity, Dual Fibre Reinforced Concrete, Finite Element Analysis, Flexural Behaviour, Hybrid Fibre, Polypropylene Fibres, Steel Fibres.**

I. INTRODUCTION

Concrete ranks among the most extensively utilized construction materials globally, valued for its high compressive strength, durability, and construction versatility. Its application spans buildings, bridges, pavements, dams, and various civil engineering infrastructure projects. However, conventional concrete exhibits significant limitations, including low tensile strength and brittle behaviour, which precipitate sudden cracking and catastrophic failure under tensile and flexural loading conditions.

The incorporation of discrete fibres distributed randomly throughout the concrete matrix has emerged as an effective strategy to overcome these inherent limitations. Fibre Reinforced Concrete (FRC) represents a composite material wherein fibres serve as crack arresters, bridging crack surfaces and transferring stresses to delay propagation and enhance post-cracking performance. Among the various fibre types available, steel fibres and polypropylene fibres have gained widespread acceptance due to their excellent mechanical properties and cost-effectiveness.

Steel fibres significantly improve load-carrying capacity, flexural strength, and post-cracking resistance, while polypropylene fibres effectively reduce micro cracking and plastic shrinkage cracking, enhancing toughness and durability. The combination of these fibres in concrete forms Dual Fibre Reinforced Concrete (DFRC), also termed hybrid fibre reinforced concrete, which provides synergistic benefits by simultaneously controlling both macro cracks and micro cracks.

The advancement of computational tools has facilitated comprehensive investigation of nonlinear structural behaviour through Finite Element Analysis (FEA). Abaqus stands as one of the most widely employed software packages for nonlinear structural analysis, offering robust capabilities to simulate cracking, crushing, plastic deformation, and damage behaviour of concrete materials. The Concrete Damage Plasticity (CDP) model within Abaqus enables realistic simulation of reinforced concrete structures subjected to diverse loading conditions.

A. Research Significance and Objectives

The present study aims to conduct finite element analysis of dual fibre reinforced concrete beams using Abaqus to investigate the influence of steel and polypropylene fibres on flexural behaviour and structural performance. The specific objectives include:

1. To develop finite element models of reinforced concrete beams incorporating steel fibres, polypropylene fibres, and their combination using Abaqus software.
2. To define material behaviour utilizing the Concrete Damage Plasticity (CDP) model.
3. To investigate load-displacement behaviour, crack propagation, and damage characteristics of various fibre-reinforced concrete beams.
4. To compare the structural performance of different fibre combinations.
5. To validate numerical results with published experimental literature.

II. LITERATURE REVIEW

Ming Zhou et al. (2024) : The study focused on the interfacial transition zones (ITZs) in Dual fiber-reinforced concrete (HFRC), specifically examining the combined effects of steel fibers (SF) and polypropylene fibers (PF) on mechanical and fracture properties.The authors reported that Dual fibers significantly influence ITZ fracture behavior. Through splitting tensile tests (ST) and three-point bending tests (TPB), they found that fiber type and volume fraction strongly affect tensile strength, fracture toughness, and fracture energy. For example, the mix with 0.4% PF + 1.0% SF was recommended as optimal, while increasing steel fiber content to 1.5% with the same PF proportion led to a 30% decrease in fracture toughness and fracture energy. Microstructural analysis using scanning electron microscopy (SEM) revealed that fiber type alters ITZ micromorphology, with steel and polypropylene fibers influencing crack propagation differently. The study concluded that excessive content of a single fiber reduces ITZ strength and stiffness, while balanced hybrid fiber proportions improve ductility and durability. This work provides valuable insights into designing HFRC with improved fracture resistance and durability.

Darwin La Torre Esquivel et al. (2025) : the authors reported a comparative investigation into the flexural performance of reinforced concrete beams with low reinforcement ratios, incorporating either steel fibers or polypropylene fibers. They tested beams of two sizes (1.60 m and 4.00 m) with varying fiber volumes (0.33%, 0.66%, and 1.00%) to evaluate behavior at both the serviceability limit state (SLS) and the ultimate limit state (ULS).Their findings showed that steel fibers significantly increased postcracking stiffness and load capacity but reduced ductility due to localized cracking, while polypropylene fibers provided better crack distribution and maintained ductility with moderate strength gains.

Larger beams demonstrated improved strain redistribution, reducing ductility loss compared to smaller beams. Overall, the authors concluded that polypropylene fibers are a promising alternative tosteel fibers in beams with low reinforcement ratios, particularly for long-span applications where ductility is essential.

M. Qasim et al. (2023) : The study investigated the use of steel and polyvinyl-alcohol hybrid fibre reinforced engineered cementitious composite (SPH-ECC) layers with embedded reinforcement bars to strengthen full-scale reinforced concrete (RC) beams.The authors reported experimental and numerical findings from four-point bending tests on one unstrengthened control beam and three beams strengthened with different SPH-ECC configurations. Results showed that strengthened beams achieved 125% to 210% of the flexural strength of the control beam, with improved crack width control and ductility. Among the tested configurations, the U-shaped SPH-ECC encasement (SB-3) provided the highest peak load (354 kN, 210% of control) and avoided significant interfacial debonding, unlike SB-1 which suffered premature bond failure. Numerical modelling using ABAQUS with a surface-to-surface cohesive model successfully replicated experimental behaviors, including interfacial bond-slip. Overall, the study demonstrated that embedding reinforcement bars within SPH-ECC layers significantly enhances flexural strength, ductility, and bond performance, making SPH-ECC a promising material for durable strengthening of RC structures.

Sarah Khaleel Ibrahim et al. (2023) : reported a combined experimental and numerical investigation into the performance of hybrid fibre-reinforced concrete (HPRC) deep beams. The study explored how different mixes of steel fibres (SF) and polypropylene fibres (PPF) influenced the strength, ductility, crack distribution, and deflection of simply supported reinforced concrete deep beams. Two beams were tested experimentally—one with normal concrete and another with hybrid fibre concrete—while six different concrete mixes with varying fibre percentages were prepared to calibrate numerical models using the Concrete Damage Plasticity (CDP) model in ABAQUS. Results showed that fibres significantly enhanced load-bearing capacity and ductility compared to plain concrete. The optimal fibre mix was identified as 0.75% SF and 0.25% PPF, which improved strength and crack control, while higher PPF content was more effective in reducing deflection. The research highlighted the novelty of integrating experimental validation with numerical calibration, offering practical insights for engineers on selecting fibre combinations to improve reinforced concrete deep beam performance.

S.R. Shashikumara et al (2023) : investigated how polypropylene (PP) and steel fibers affect the flexural performance of high-strength reinforced concrete beams. The study tested beams with optimized fiber contents—0.05% PP and 0.75% steel—against controlled concrete (CC) specimens under four-point bending. Results showed that fiber inclusion significantly improved load-bearing capacity, ductility, toughness, and energy absorption. At yield, PFRC beams carried 70.5 kN compared to 58.4 kN for CC, while SFRC beams reached 110.6 kN. Ultimate load capacity increased by 12.1 kN in PFRC and 50.1 kN in SFRC. Flexural toughness improved by 14.86% with PP fibers and 23.51% with steel fibers. Energy absorption capacity rose by 689.57 kN-mm in PFRC and 2271.89 kN-mm in SFRC, with SFRC showing the highest post-peak ductility and crack branching behavior. The authors concluded that steel fibers provide superior strength and toughness, while polypropylene fibers enhance crack control and ductility, making hybrid fiber strategies promising for high-strength concrete applications.

III. METHODOLOGY

A. Materials and Properties

1) Concrete Constituents

Ordinary Portland Cement (OPC) with specific gravity of 3.1 served as the primary binding material. Natural river sand conforming to IS 383:1970 specifications with specific gravity of 2.7 was employed as fine aggregate. Crushed angular coarse aggregate conforming to IS 383:1970 with specific gravity of 2.7 provided strength and dimensional stability. Potable clean water free from impurities was utilized for mixing and curing.

2) Steel Fibres

Hooked-end steel fibres with properties presented in Table I were employed to improve flexural strength and toughness. Steel fibres bridge cracks and enhance post-cracking behaviour through effective stress transfer across crack surfaces.

TABLE I: STEEL FIBRE PROPERTIES

Properties	Value
Fibre Type	Hooke-end steel Fibre
Length	30mm
Diameter	0.5mm
Aspect Ratio	60
Elastic Modulus	200 GPa
Tensile Strength	1100 MPa
Density	7850 kg/m^3

3) Polypropylene Fibres

Monofilament polypropylene fibres were utilized to control micro-cracks and improve crack resistance. Table II presents the properties of polypropylene fibres employed in this study.

TABLE II: POLYPROPYLENE FIBRE PROPERTIES

Properties	Value
Fibre Type	Polypropylene Fibre
Length	12 mm
Diameter	18-40 µm
Elastic Modulus	3-5 GPa
Density	910 kg/m^3

4) Reinforcement Steel

Fe500 grade reinforcement steel bars with properties detailed in Table III were employed to improve tensile resistance and flexural capacity of beam specimens.

TABLE III: REINFORCEMENT STEEL PROPERTIES

Properties	Value
Steel Grade	Fe500
Elastic Modulus	200000 MPa
Yield Strength	500 MPa
Ultimate Strength	600 MPa
Poisson Ratio	0.3
Density	7850 kg/m^3

B. Concrete Mix Proportions

Concrete mix proportions were selected based on standard concrete mix design procedures for M30 grade concrete, as presented in Table IV. Fibres were added based on volume fraction.

TABLE IV: MIX DESIGN PROPORTIONS

Material	Ratio
Cement	1
Fine Aggregate	1.5
Coarse Aggregate	3
Water-Cement Ratio	0.45

C. Material Properties for Finite Element Analysis

Material properties adopted in the finite element analysis were obtained from published experimental literature, as summarized in Table V.

Property	RC	SFRC	PP FRC	DFRC
Density (kg/m^3)	2400	2420	2410	2450
Elastic Modulus (GPa)	26.03	25.21	25.22	25.64
Poisson Ratio	0.187	0.187	0.187	0.187
Compressive Strength (MPa)	38	42	40	46
Tensile Strength (MPa)	2.62	2.93	2.71	3.39

IV. FINITE ELEMENT MODELING

A. General Modeling Approach

The finite element analysis was conducted using Abaqus software following systematic procedures: creation of concrete beam geometry, modeling of reinforcement bars, definition of material properties, CDP model definition, section assignment, assembly, embedded region constraint definition, element type selection, meshing, analysis step definition, loading and boundary condition application, job creation, and result extraction.

B. Assumptions

The following assumptions were considered during finite element analysis:

- Concrete was assumed homogeneous and isotropic.
- Perfect bond was assumed between concrete and reinforcement.
- Steel fibres and polypropylene fibres were not modeled individually.
- Reinforcement bars were embedded within the concrete beam.
- Static loading conditions were considered throughout the analysis.

C. Beam Geometry and Reinforcement Details

The concrete beam was modeled as a three-dimensional deformable solid using Abaqus. Beam dimensions are presented in Table VI, while reinforcement details are summarized in Table VII.

TABLE VI: BEAM DIMENSIONS

Parameter	Value
Length	1500mm
Width	150
Depth	250

TABLE VII: REINFORCEMENT DETAILS

Rebar Type	Diameter	Quantity
Bottom Main Bar	12mm	2
Top Bars	10mm	2
Stirrup's	10mm	@200mm

D. Concrete Damage Plasticity (CDP) Model

The CDP model available in Abaqus was employed to simulate nonlinear behaviour of concrete under tension and compression. The model accounts for tensile cracking, compression crushing, plastic deformation, damage evolution, and stiffness degradation. CDP parameters adopted in the analysis are presented in Table VIII.

TABLE VIII: CONCRETE DAMAGE PLASTICITY PARAMETERS

Parameter	Value
Dilation Angle	36°
Eccentricity	0.1
Fb0/fc0	1.16
K	0.667
Viscosity Parameter	0.0001

E. Element Types and Meshing

C3D8R elements (8-node reduced integration solid elements) were employed for concrete modeling, while T3D2 elements (3-node truss elements) were utilized for reinforcement. A structured mesh with 50 mm element size was adopted for the concrete beam model.

F. Loading and Boundary Conditions

Three-point bending loading was adopted to evaluate flexural behaviour, providing a constant moment region for effective evaluation of crack propagation and flexural performance. Simply supported boundary conditions were provided, with pinned support at the both ends.

G. Analysis Parameters

A static general analysis step was employed for nonlinear analysis with geometry nonlinearity activated. Step parameters are presented in Table IX.

TABLE IX: STEP PARAMETERS

Parameter	Value
Step Type	Static General
Nonlinear Geometry	ON
Initial Increments	o.o1
Minimum Increments	1E-5
Maximum Increments	0.1

V. RESULTS AND DISCUSSION

A. Load-Displacement Behaviour

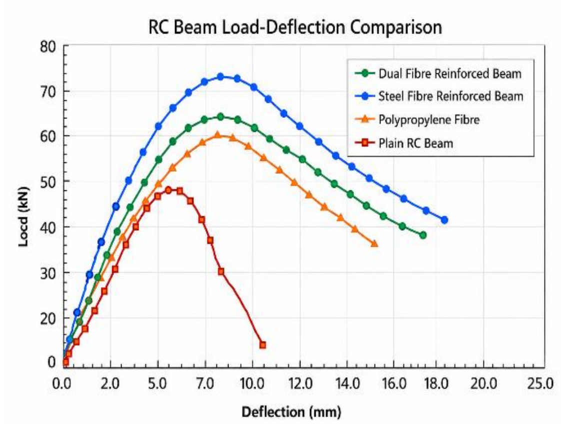
Load-displacement relationships serve as key metrics for assessing flexural capacity of reinforced concrete beams. Finite element results demonstrated that fibre incorporation substantially enhanced structural response. The dual FRC beam displayed the greatest load-bearing capacity and superior ductility relative to other variants. Load-displacement summaries for all beam types are presented in Table X and Fig. 1.

TABLE X: LOAD-DISPLACEMENT SUMMARY

Beam Type	Ultimate Load	Deflection
Plain RC Beam	524.2	4.2
Steel FRC Beam	645.8	5.8
PP FRC Beam	605.1	5.1
DFRC Beam	727.0	7.0

The plain concrete beam experienced abrupt failure post-Ultimate load due to brittle cracking nature. Conversely, FRC beams exhibited progressive failure with enhanced post-crack performance, enabling greater energy absorption and ductility. Quantitative comparisons demonstrate substantial improvements:

- Steel FRC beam exhibited 23% increase in peak load (645.8 kN vs. 524.2 kN) and 38% greater deflection at peak load (5.8 mm vs. 4.2 mm) compared to plain concrete.
- Polypropylene FRC beam showed 15% higher peak load (605.1 kN vs. 524.2 kN) and 22% increased deflection (5.1 mm vs. 4.2 mm).
- Dual FRC beam achieved most substantial improvements with 38% higher peak load (727.0 kN vs. 524.2 kN) and 67% greater deflection (7.0 mm vs. 4.2 mm)
-



These gains stem from synergistic effects of steel fibres' crack-bridging capability and polypropylene fibres' micro crack mitigation, collectively improving load transfer and delaying failure.

B. Stress Distribution Analysis

Abaqus stress contours highlighted zones of stress buildup in beams under loading. Peak compressive stresses appeared near loading points and compression zones, while tensile stresses concentrated at beam lower sections. Plain concrete displayed intense localized stresses and swift cracking. FRC beams showed more uniform stress distribution due to fibre bridging, effectively transferring stresses across cracks. The dual FRC beam provided superior stress redistribution, postponed crack growth, and lower stress peaks, attributable to steel fibres enhancing tensile resistance and polypropylene fibres suppressing micro-crack initiation and propagation.

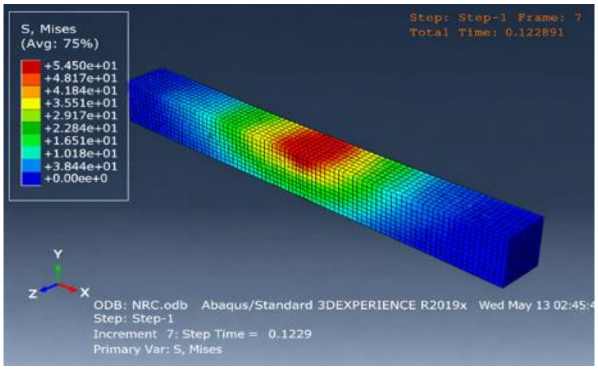


Figure 1 Plain RCC Beam

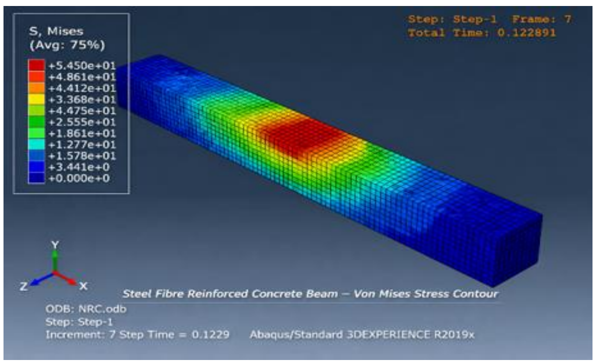


Figure 2 Steel Fibre Reinforced Concrete Beam

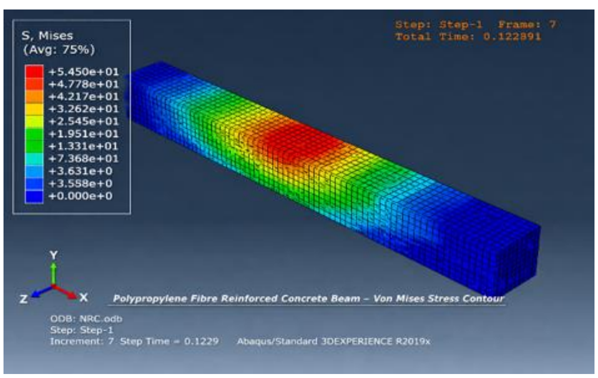


Figure 3 Polypropylene Fibre Reinforced Concrete Beam

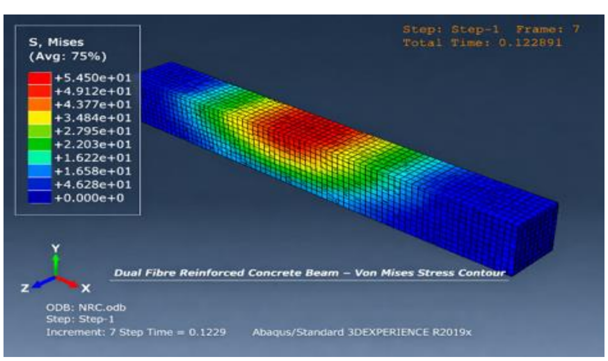


Figure 4 Dual Fibre Reinforced Concrete Beam

C. Comparative Analysis of Fibre Combinations

Steel fibres primarily boosted flexural strength, load capacity, and post-cracking behaviour through effective crack bridging and tensile load transfer. Polypropylene fibres enhanced crack control, micro crack resistance, and ductility by maintaining concrete matrix cohesion and reducing crack propagation. Their hybrid combination yielded optimal performance through combined advantages, effectively managing both micro- and macro cracks simultaneously.

TABLE XI: COMPARATIVE PERFORMANCE SUMMARY

Parameter	Plain RCC	SFRC	PPFRC	DFRC
Ultimate Load	524.2	645.8	605.1	72.0
% Increase in Ultimate Load	-	23%	15%	38%
Max Deflection	4.2	5.8	5.1	7.0
% Increase in Deflection	-	38%	22%	67%

D. Validation of Numerical Results

Abaqus results aligned well with experimental studies on dual FRC beams regarding peak load, load-displacement curves, crack patterns, and failure modes. Slight discrepancies arose from material simplifications, assumed perfect bonding, and uniform fibre placement assumptions. The validation confirmed model accuracy and reliability for predicting DFRC structural behaviour.

E. Effect of Steel Fibres

Steel fibres markedly improved flexural behaviour, yielding higher peak loads, narrower cracks, better toughness, and stronger post-cracking response. They effectively bridged cracks and transferred tensile loads across crack surfaces, enhancing overall structural integrity.

F. Effect of Polypropylene Fibres

Polypropylene fibres enhanced crack resistance and ductility by reducing micro crack initiation, propagation speed, and brittle tendencies. They maintained concrete matrix cohesion and improved durability characteristics.

G. Effect of Dual Fibre Reinforcement

Dual FRC delivered top performance across all models, with maximal load capacity, boosted ductility, delayed cracking, higher energy absorption, and stable failure. It effectively managed both micro- and macro cracks simultaneously, providing superior structural performance.

VI. CONCLUSION

A. Summary of Findings

The study on dual fibre reinforced concrete (DFRC) beams highlights significant advantages of combining steel and polypropylene fibres within the concrete matrix. Key findings are summarized as follows:

1. Steel fibres provide superior improvements in flexural strength, toughness, energy absorption, and post-cracking resistance, making them highly effective against macro cracks.
2. Polypropylene fibres are particularly effective in controlling micro cracks, reducing shrinkage, and enhancing durability, though contributing less to strength enhancement.
3. The dual fibre system synergistically combines these benefits, resulting in improved crack resistance, ductility, toughness, and delayed failure behaviour, with 38% increase in peak load and 67% greater deflection capacity compared to plain concrete.
4. Finite Element Analysis using Abaqus and the Concrete Damage Plasticity (CDP) model provides a reliable framework for simulating nonlinear behaviour, crack propagation, and damage characteristics of DFRC beams.
5. Numerical modeling offers a cost-effective and efficient alternative to experimental testing, enabling deeper insights into structural performance under flexural loading.

B. Practical Implications

The integration of steel and polypropylene fibres in reinforced concrete beams leads to more resilient and durable structural systems. DFRC demonstrates enhanced performance under static and dynamic loading, making it suitable for critical applications including bridges, pavements, seismic-resistant structures, and impact-prone environments. The validated numerical modeling approach provides engineers with a robust tool for design optimization and performance prediction.

C. Limitations and Future Research

Study limitations include:

- Fibres were not modeled individually within the concrete matrix.
- Perfect bond between concrete and reinforcement was assumed.
- Material properties were adopted from published literature.
- Environmental effects such as temperature and corrosion were not considered.
- Dynamic and fatigue loading conditions were not included.

Future research should address these limitations through comprehensive experimental validation, individual fibre modeling, and investigation of long-term durability performance under varied environmental conditions.

REFERENCES

[1] M. Zhou, X. He, H. Wang, C. Wu, J. He, and B. Wei, “Mechanical properties and microstructure of ITZs in steel and polypropylene dual fiber-reinforced concrete,” Construction and Building Materials, vol. 2024, 2024.

[2] D. La Torre Esquivel, F. de Andrade Silva, and A. A. Del Savio, “Flexural behavior of steel and polypropylene fiber-reinforced concrete beams with low longitudinal reinforcement ratios,” 2025.

[3] M. Qasim, C. K. Lee, and Y. X. Zhang, “Flexural strengthening of reinforced concrete beams using hybrid fibre reinforced engineered cementitious composite,” Engineering Structures, 2023.

[4] S. K. Ibrahim, N. A. Hadi, and M. M. Rad, “Experimental and numerical analysis of steel-polypropylene hybrid fibre reinforced concrete deep beams,” 2023.

[5] J. Blazy and R. Blazy, “Polypropylene fiber reinforced concrete and its application in creating architectural forms of public spaces,” 2021.

[6] S. R. Shashikumara, N. Pramukh, R. Abhishek, and V. K. Nagaraj, “Experimental study on the

influence of polypropylene and steel fiber on flexural behaviours of high strength concrete beams," 2023.

[7] Q. C. Minh, G. H. Nguyen, A. T. Al-Sayegh, and A. Ahmad, "Flexural response and structural efficiency of hybrid fiber-reinforced concrete slabs," 2025.

[8] M. Tawfik, A. El-said, A. Deifalla, and A. Awad, "Mechanical properties of hybrid steel-polypropylene fiber reinforced high strength concrete exposed to various temperatures," 2022.

[9] M. Qasem, M. Hasan, R. Muhamad, C.-L. Chin, and N. Alanazi, "Generalised calibration and optimization of concrete damage plasticity model for finite element simulation of cracked reinforced concrete structures," 2025.

[10] F. Sermet and A. Ozdemir, "Investigation of punching behaviour of steel and polypropylene fibre reinforced concrete slabs under normal load," 2016.

[11] Q. U. Z. Khan, M. Ali, A. Ahmad, A. Raza, and M. Iqbal, "Experimental and finite element analysis of hybrid fiber reinforced concrete two-way slabs at ultimate limit state," 2021.

[12] T. Cui, H. He, and W. Yan, "Experimental research on uniaxial compression constitutive model of hybrid fiber-reinforced cementitious composites," 2019.

[13] I. G. Shaaban, M. Said, S. U. Khan, M. Eissa, and K. Elrashidy, "Experimental and theoretical behaviour of reinforced concrete beams containing hybrid fibres," 2021.