Journal of Mines, Metals and Fuels, *73(10): 3345-3354; 2025. DOI: 10.18311/jmmf/2025/49927*

Online ISSN : 0022-2755

Journal of Mines, Metals and Fuels

Contents available at: *www.informaticsjournals.co.in/index.php/jmmf*

Concrete Crack Dynamics: A Comprehensive Analysis of Cracks on Concrete Beams

Rahul S. Chaudhari[1]*, Pranjal A. Jog[2], Ghanasham C. Sarode[3], Ujwal Shirode[2] and Deepika Sarode[4]

[1]Department of Civil Engineering, Pimpri Chinchwad College of Engineering, Pune - 411044, Maharashtra, India; rahul.chaudhari@pccoepune.org

[2]Department of Electronics and Telecommunication, Pimpri Chinchwad College of Engineering, Pune - 411014, Maharashtra, India

[3]Department of Civil Engineering, Dr. D.Y. Patil Institute of Technology, Pune - 411018, Maharashtra, India

[4]Department of First Year Engineering, Dr. D.Y. Patil Institute of Technology, Pune - 411018, Maharashtra, India

Abstract

This study presents a detailed investigation into the mechanical performance and fracture behaviour of ordinary concrete in comparison with Fibre Reinforced Concrete (FRC) incorporating Polypropylene and Steel fibres. A thorough experimental methodology was employed, encompassing the design and preparation of concrete mixtures, followed by advanced analysis of fracture patterns and microstructural responses using ZEISS imaging software. Key parameters such as crack propagation, strain development, and failure mechanisms were systematically evaluated. The experimental results revealed that Steel Fibre Reinforced Concrete exhibited the most pronounced crack width, measuring 4.87 mm, while Polypropylene Fibre Reinforced Concrete recorded a crack width of 2.64 mm, and ordinary concrete showed the smallest crack width of 1.96 mm. In terms of strain behaviour, Steel FRC achieved the highest maximum strain value of 49.99 %, indicating superior deformation capacity. This was followed by Polypropylene FRC at 21.42%, and ordinary concrete with a significantly lower strain capacity of 7.98%. Statistical analysis confirmed a significant variation in strain capacity between the two types of Fibre-reinforced concrete, particularly emphasising the superior performance of steel Fibres in enhancing ductility and controlling crack expansion. These findings underscore the benefits of Fibre reinforcement—especially with steel Fibres—in improving the structural resilience and durability of concrete, making it a promising approach for advanced civil engineering applications and infrastructure design.

Major Findings: *The study confirms that Steel Fibre Reinforced Concrete (SFRC) exhibits the highest strain capacity and the widest crack width, indicating superior energy absorption and load-bearing capability. Polypropylene Fibre Reinforced Concrete (PFRC) provides moderate improvement in crack control and strain capacity compared to ordinary concrete, enhancing its toughness. Statistical evidence supports that Fibre reinforcement—especially with steel Fibres—significantly improves crack resistance, strain distribution, and overall structural integrity of concrete.*

Keywords: *Crack Propagation, Fibre-Reinforced Concrete, Fracture characteristics, Strain Distribution*

1.0 Introduction

Crack propagation in concrete involves the expansion and spread of cracks within concrete structures, which can result from factors like tensile stresses, thermal changes, and chemical reactions. These cracks can manifest as one-

**Author for correspondence*

dimensional line cracks, two-dimensional surface cracks, or three-dimensional volume cracks, posing risks of structural failure if left unaddressed. One common method for studying crack propagation is through probabilistic analysis and simulation, which considers uncertainties related to concrete materials and loading conditions. Concrete, as the most globally utilised construction material, inherently possesses a low tensile strength, rendering structural elements susceptible to cracking even under typical service loads[1]. These cracks, while sometimes superficial, can significantly compromise the structural integrity, durability, and overall performance of concrete infrastructure[2]. Understanding the underlying mechanisms governing crack initiation, propagation, and the long-term effects on concrete structures is therefore crucial for ensuring safety and serviceability[3]. The brittle nature of concrete implies that once a crack forms, stress redistribution becomes limited, potentially leading to rapid failure[4]. Fibre reinforcement techniques have been developed to overcome these limitations by enhancing tensile and flexural strength, but cracking is still a common concern[5]. Concrete structures that are well designed and use high-quality materials generally require little maintenance or repair unless exposed to particularly aggressive conditions[6].

The development of cracks in concrete provides pathways for moisture and aggressive chemical species, exacerbating deterioration processes such as corrosion of steel reinforcement, alkali-aggregate reactions, and freeze-thaw damage[7]. The complex interplay of these deterioration mechanisms can lead to a substantial reduction in the lifespan of concrete structures, necessitating costly repairs or even complete replacement. The origins of concrete slab cracks are multifaceted, stemming from design flaws, construction errors, and the inherent characteristics of the concrete mixture itself[8]. Given that concrete has a low tensile strength, reinforced concrete beams are highly prone to cracking, which causes slippage between the concrete and the reinforcing steel[9]. Moreover, dynamic loads, such as those resulting from blasts or impacts, can induce complex damage patterns in concrete structures, highlighting the importance of understanding material behaviour under high strain rates[10]. The issue of concrete creep is becoming a major concern, posing a threat to the structural integrity, quality, and long-term stability of concrete structures, as it can diminish the maximum tensile stress[11].

Furthermore, the durability of concrete and other cementitious materials is inherently tied to their microstructure[12]. This includes the porosity and the water-to-cement ratio, which influence the transport of deleterious substances[13]. Factors such as steel corrosion, freeze-thaw cycles, exposure to soft water, elevated temperatures, and chemical erosion significantly affect the durability of reinforced concrete, necessitating a comprehensive understanding to control concrete deterioration, reduce structural repair costs, and minimise life cycle costs[14]. To improve the situation, the use of techniques like incorporating diverse concentrations of Anthocleista djalonensis leaf extract into steel-reinforced concrete can result in a maximum inhibition efficiency of 97.43% at a concentration of 0.4167%[15]. The presence of dusty and clay particles within concrete mixtures can elevate the concrete's water demand and amplify both shrinkage and creep, which subsequently compromises its durability[16]. The durability of concrete is defined by its capacity to withstand weathering, chemical attacks, abrasion, and any other deterioration processes while maintaining its original form, quality, and serviceability in its intended environment[17].

The use of High-Performance Concrete has become widespread, but even with its enhanced strength, concrete remains susceptible to cracking due to its low tensile strength and limited strain capacity[18]. Therefore, comprehending the factors influencing crack development and propagation in concrete beams is essential for developing effective strategies for crack control and structural health monitoring. While advanced materials such as Fibre-reinforced polymers and low-carbon cement show promise for enhancing concrete durability and sustainability, a comprehensive understanding of their real-world performance, especially under variable environmental conditions and in ageing infrastructure, is lacking[19]. The rate at which water is absorbed by wet concrete or other liquids primarily depends on absorption caused by capillary action[20]. When concrete is submerged in water, interconnected pores become filled with liquid. For concrete, the issue of durability is greatly influenced by its permeability, a crucial factor intimately connected to the quantity of mixing water utilized[21].

Ultimately, by gaining a deeper understanding of concrete crack dynamics, engineers and researchers can work towards developing more resilient, durable, and sustainable concrete structures that meet the evolving demands of modern society[22]. Moreover, the use of self-healing agents, like bacteria, that can autonomously repair cracks in concrete, is receiving increased attention as a mechanism that contributes to a longer service life of concrete structures[23]. The hardening of concrete is a result of the chemical reaction between the cement and water, which continues over an extended period, leading to increased strength with age[24]. Increasing the quantity of fly ash and silica fume in concrete enhances its resistance to chloride penetration and water absorption. Additionally, minimising the cement's water-to-cement ratio can have similar beneficial effects[25–37].

2.0 Literature Survey

This section includes the research insights of the researchers. Those are summarised in a tabular format in Table 1.

3.0 Methodology

This section includes the methodology adopted for this experimental work, as shown in Figure 1.

The steps include,

Step 1: Literature Survey: Detailed literature was studied to understand the processes adopted by the researchers. A few of them are summarised in the above section.

Step 2: To prepare the mix design, the materials were tested as per the Indian Standard. Mix

Table 1. Crack propagation in concrete

Aspect	Description	Examples	Research Insights
Crack Types & Causes	Cracks develop due to tensile stress, thermal shifts, and chemical reactions; classified as line, surface, or volume cracks.	Cracks from shrinkage, construction defects, or load stress in beams and slabs.	Probabilistic modeling helps simulate and predict crack propagation under uncertain conditions.
Impact on Structures	Compromises integrity, durability, and service life; leads to corrosion, alkali-aggregate reaction, and freeze-thaw damage.	Steel reinforcement corrosion due to water ingress through cracks.	Design flaws and low tensile strength of concrete promote frequent cracking in service.
Mechanisms & Properties	Low tensile strength, brittle nature, and poor strain capacity cause stress redistribution issues and rapid crack growth.	Stress concentration at crack tips leads to brittle fracture under dynamic loads.	Concrete's creep behaviour reduces effective tensile stress over time.
Durability Challenges	Affected by porosity, water-cement ratio, corrosion, freeze-thaw, and chemical erosion; increases life cycle costs.	Dust and clay in a mixture elevate shrinkage and creep; soft water causes leaching.	Durability is closely linked to permeability and microstructural characteristics.
Innovative Solutions	Incorporation of Fibres, leaf extracts, self-healing bacteria, and admixtures like fly ash or silica fume enhances performance.	Use of Anthocleista djalonensis extract, bacteria-induced healing, and low w/c ratio.	Need for performance monitoring of advanced materials under real-world conditions.

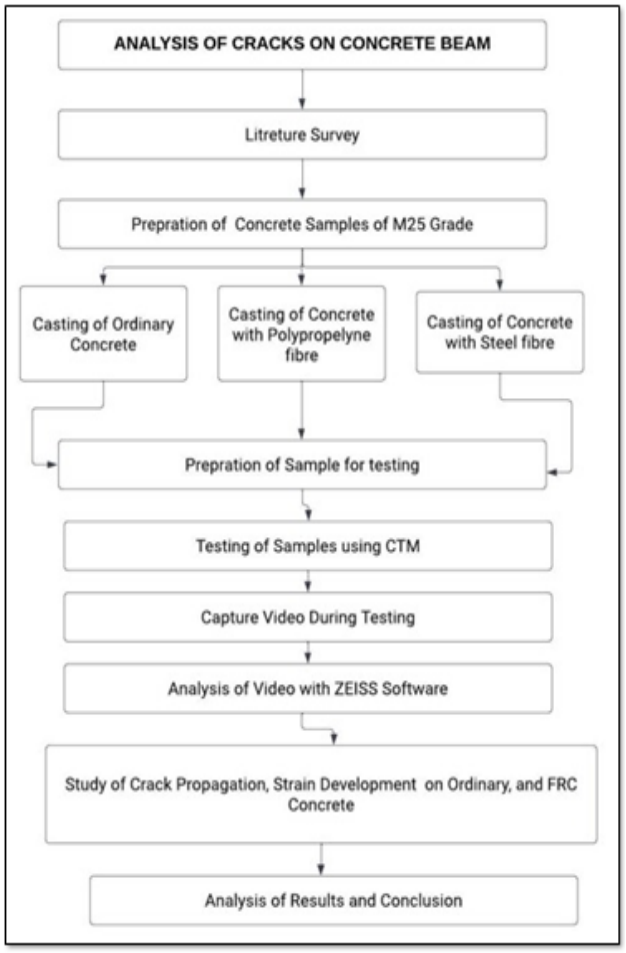


Figure 1. Methodology for the work.

Designs were prepared, and concrete beams were cast for M25 grade.

Step 3: Six samples were cast of ordinary concrete, Fibre-reinforced concrete (Polypropylene and Steel)

Step 4: The sample was prepared for the test by marking dots and applying colour. This help software to identify the surface for analysis.

Step 5: The samples were tested using a Concrete Testing Machine (UTM). While doing this, a video was recorded for each sample.

Step 6: The Input to the ZEISS software was given in the form of a video.

Step 7: Analysis for the crack propagation, strain, etc, was carried out.

Step 8: Interpretation of results and conclusion was done.

4.0 Experimental Programme

The concrete mix was prepared for M25 grade according to the IS 456:2000. The details of the mix design are as under (Table 2)

Table 2. Mix Design for M25 concrete

Material	Quantity (kg/m^3)
Cement	350 kg
Sand	350 kg
Aggregate	700 kg
Water(w/c ratio used is 0.45)	158 litres
Polypropylene Fibre	1.5 % weight Cement(IS10262:2009)
Steel Fibre	1.5 % weight Cement(IS10262:2009)

Six beams were cast for each type of concrete using the above mix proportion. The size of the concrete beam was 15cm x 15 cm x 70 cm.

4.1 Analysis using ZEISS

To get the concrete crack dynamics, input is required from the ZEISS as a video. The video was recorded for each sample during testing.



Figure 2. Preparation of the sample for the test.

The process adopted for the analysis is as follows,

Step 1: Preparation of Sample and Setup

This step includes cleaning the sample (a) using polish paper, demarcation of dots for identification of surface by ZEISS (b) and setup for getting video during the test up to the failure of the sample (c) as shown in Figure 2.

Step 2: Working with ZEISS

This includes six sub-steps. The details of those are in Figure 3

Step 3: Outcome after step 6 from Figure 3.

After uploading the video, no. The images generated per sample are as follows,

The outcome in the form of images at Crack initiation, Crack propagation and Crack at failure for ordinary and FRP are shown below,

For ordinary concrete:

Table 2. Number of images generated per sample by ZEISS

Type of Concrete	Sample No.	No of images per second	Total Images Generated
Ordinary Concrete	1	30	4500
	2	30	4650
	3	30	4380
Polypropylene Fibre Concrete	1	30	4450
	2	30	4820
	3	30	4680
Steel fibre Concrete	1	30	4520
	2	30	4690
	3	30	4620

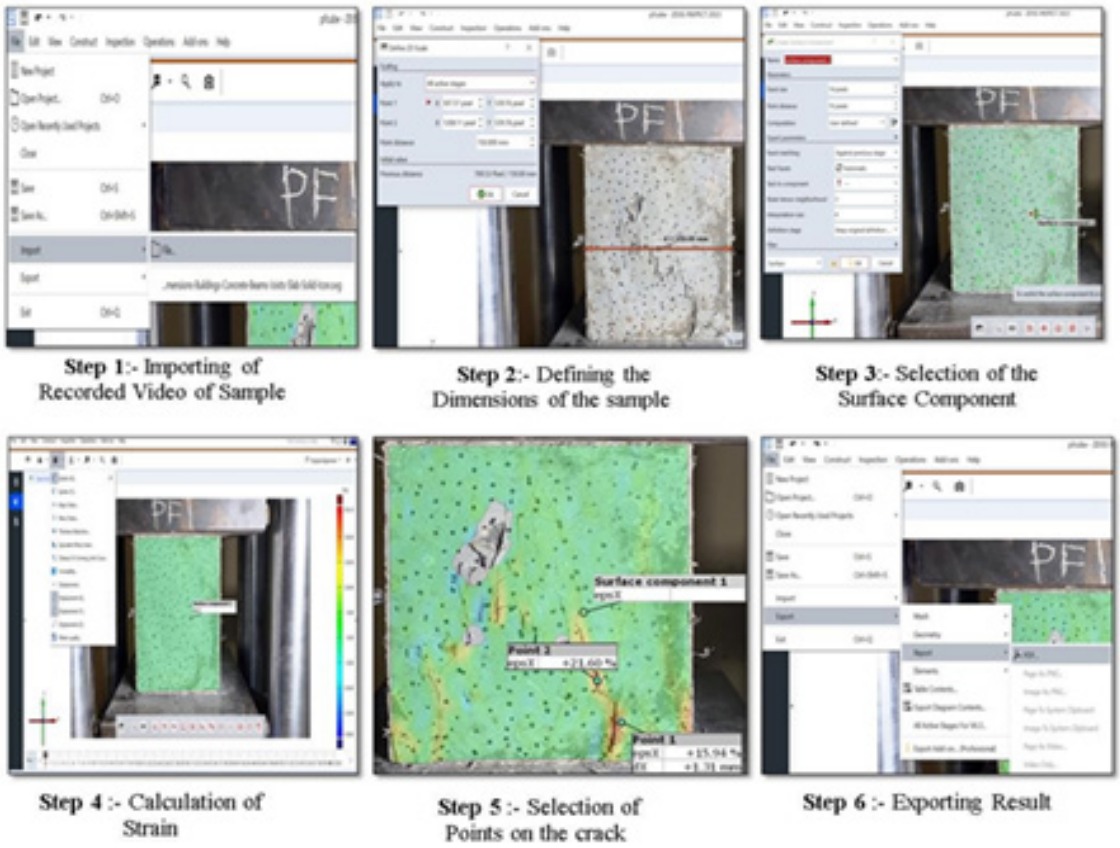


Figure 3. Steps for analysis in ZEISS software.

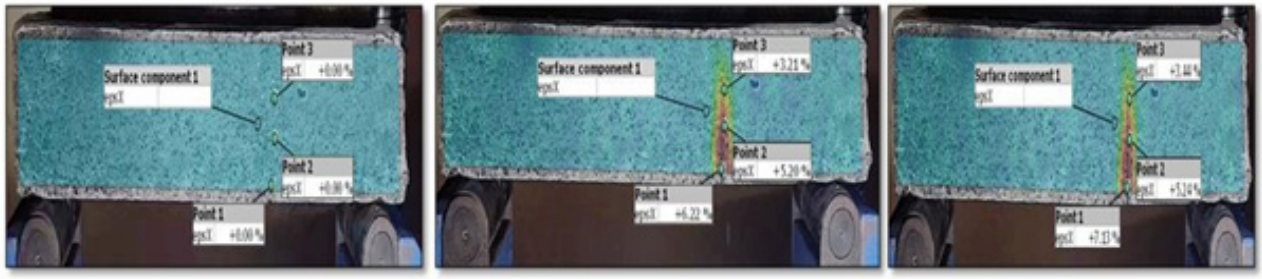


Figure 4. **(a).** For FRC (Polypropylene fibre is used).

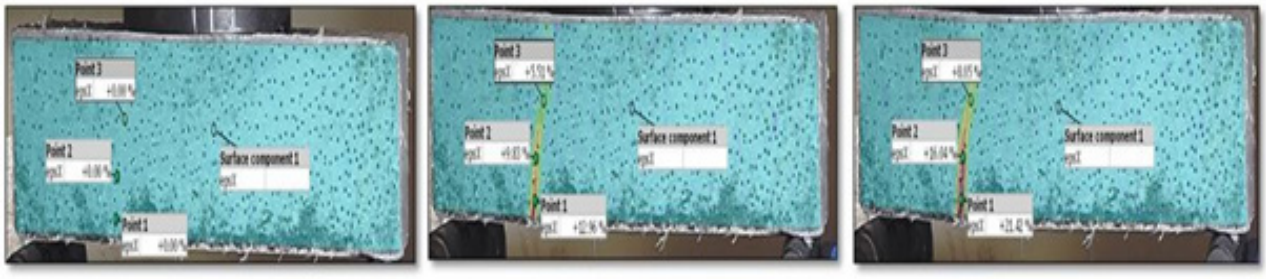


Figure 4. **(b).** For FRC (Steel fibres are used).

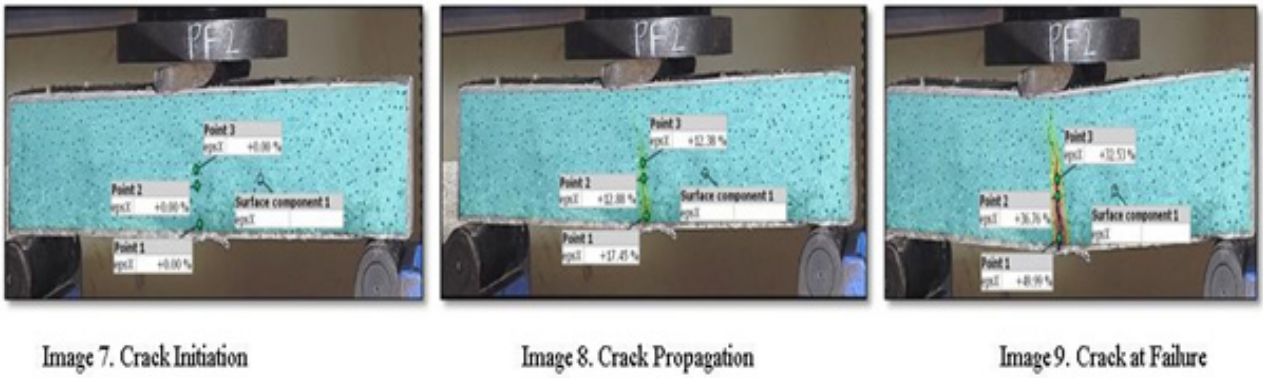


Figure 4. **(c).** Crack initiation, propagation and failure of samples.

Figure 4 illustrates the progression of cracks in three concrete types under loading. Ordinary concrete exhibits wider cracks and brittle failure, while Polypropylene FRC shows improved crack control with moderate propagation. Steel FRC demonstrates the best performance, with minimal crack width and delayed failure, indicating superior toughness and strain resistance.

Step 4: Strain Vs Time

The results generated for strain vs Time for all three different types of concrete are shown in Figure 5.

Figure 5 shows the strain vs. time graphs for ordinary, polypropylene, and steel Fibre-reinforced concrete. Ordinary concrete displays a sudden, steep rise in strain, indicating brittle failure shortly after crack initiation. Polypropylene FRC shows a gradual and nonlinear strain development, suggesting improved ductility

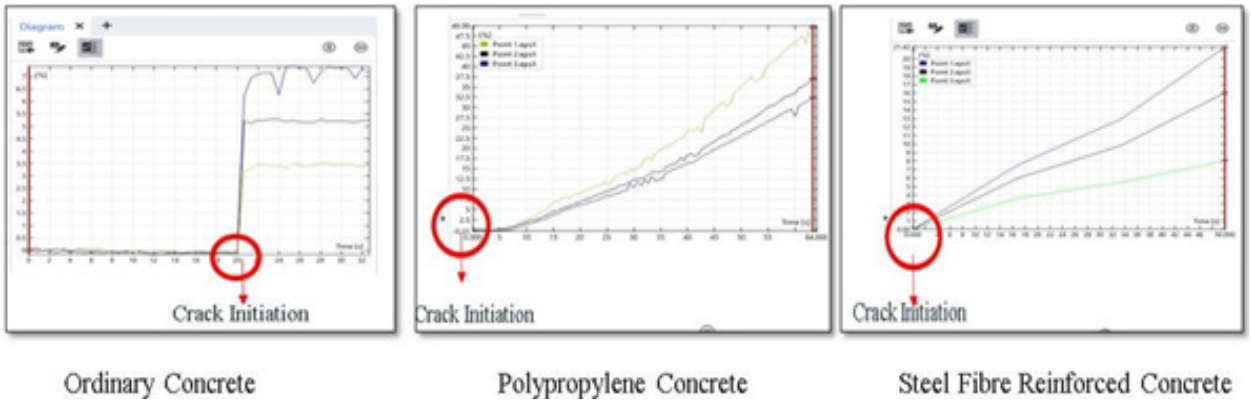


Figure 5. Strain vs. time graph for all three types of concrete.

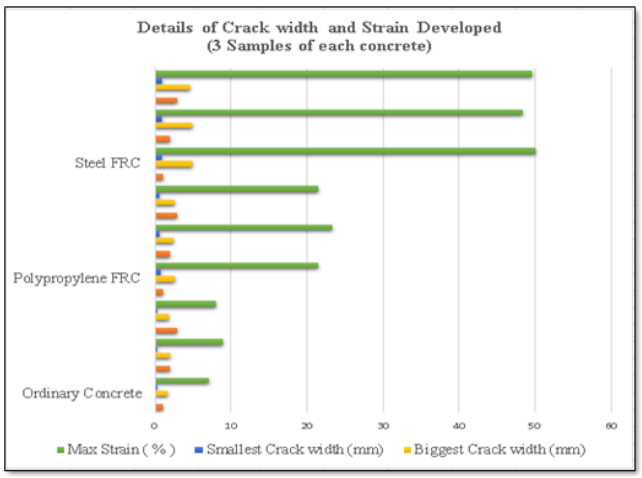


Figure 6. Summary of crack width and strain.

and delayed failure. Steel FRC exhibits the smoothest and most progressive strain increase, confirming superior crack-bridging capability and maximum strain resistance.

Step 5: Summarisation of results for all samples

Figure 6 shows a summary of the Biggest Crack width (mm), the Smallest Crack width (mm) and max Strain (%) for all samples. It compares maximum strain, smallest crack width, and biggest crack width for ordinary, polypropylene, and steel Fibre-reinforced concrete. Steel FRC shows the highest strain (~50%) and widest cracks (~4.8 mm), indicating its ability to endure more deformation before failure. Polypropylene FRC demonstrates moderate performance in both crack control and strain capacity. Ordinary concrete has the lowest strain and smallest crack widths, but it fails in a brittle manner with minimal energy absorption.

5.0 Result

The result is summarised for the different types of concrete concerning the figures as follows,

5.1 For Figure 4 (a, b & c)

5.1.1 Ordinary Concrete

- Macro-cracking was observed under loading due to its inherent brittleness.
- Crack widths tend to be wider owing to limited crack-bridging mechanisms.
- Displays lower resistance to crack propagation.
- Demonstrates lower toughness, flexural strength, and impact resistance attributed to the absence of Fibre reinforcement.

5.1.2 Polypropylene Fibre Concrete

- Mitigation of macro-cracking under loading attributed to the bridging and crack-arresting properties of polypropylene Fibres.
- Crack widths are notably narrower compared to ordinary concrete, indicating enhanced crack control.
- Exhibits moderate resistance to crack propagation owing to the restraining effect of Fibres on crack growth.

- Displays a moderate improvement in toughness, flexural strength, and impact resistance due to Fibre reinforcement.

5.1.3 Steel Fibre Concrete

- Demonstrates effective suppression of macro-cracking under loading due to the bridging and crack-bridging properties of steel Fibres.
- Crack widths are significantly narrower compared to both ordinary and polypropylene Fibre concrete, indicating superior crack control.
- Exhibits high resistance to crack propagation attributed to the high tensile strength and stiffness of steel Fibres, leading to limited crack opening and propagation.
- Displays high toughness, flexural strength, and impact resistance attributed to the synergistic effect of steel Fibres and the cementitious matrix.

5.2 Figure 5

5.2.1 For Ordinary Concrete

- The crack initiation started at 70% of the ultimate load
- The steep slope indicates that there is no bridging to crack propagation; it indicates a brittle failure of the concrete.

5.2.2 For Polypropylene Concrete

- The crack initiation started at 75% of the ultimate load
- The non-linear strain vs time graph across the different loading stages highlights the beneficial role of the polypropylene fibres in enhancing the fracture performance and delaying the onset of failure in the concrete.

5.2.3 For Steel Fibre Reinforced Concrete

- The crack initiation started at 80% of the ultimate load
- In the initial stages, the strain observed was less, indicating the bridging effect of the steel fibres on the crack propagation. A steep increase in the end was observed, indicating concrete failure.

6.0 Conclusion

This experimental investigation was conducted to assess and compare the mechanical behaviour and fracture properties of plain concrete and Fibre Reinforced Concretes (FRCs) with the optimised mix design for Polypropylene (PP) and Steel (ST) Fibres. The process followed was systematic from mix design to fracture analysis using ZEISS software for analysis of crack propagation, strain behaviour and failure modes. The key findings are:

- Statistical analysis results indicated that significantly different crack widths and strain behaviours among different concretes were observed.
- It was observed that the average maximum crack width was the highest in Steel FRC (4.82 mm), followed by Polypropylene FRC at 2.56 mm, and at 1.85 mm for normal concrete, indicating higher strength bearing capacity of Steel FRC and brittle failure of normal concrete.
- In the case of strain, the Polypropylene FRC has the highest average peak of 22.04%, followed by Steel FRC at 49.33% and ordinary concrete with the lowest at 8.026%.
- The strain capacity between Polypropylene and Steel FRC was significantly different ($p < 0.05$), suggesting an influence of Fibre type on mechanical behaviour.
- In conclusion, the study verifies the significant advantages of Fibre reinforcement (particularly with steel Fibre) in terms of crack control and an increase in strain capacity of concrete structures.

7.0 References

1. Mohamad RM. Fracture-based nonlinear model for reinforced concrete beams. Int J Geomate. 2020; 18(65). https://doi.org/10.21660/2020.65.66197
2. Bhargava K, Ghosh A, Mori Y, Ramanujam S. Analytical model for time to cover cracking in RC structures due to rebar corrosion. Nucl Eng Des. 2005; 236(11):1123. https://doi.org/10.1016/j.nucengdes.2005.10.011
3. Kaveh H, Alhajj R. Recent advances in crack detection technologies for structures: a survey of 2022-2023

literature. Front Built Environ. 2024; 10. https://doi.org/10.3389/fbuil.2024.1321634
4. Hadipramana J, Riza FV, Amirsyah T, Mokhatar SN, Ardiansyah M. Study on workability high high-strength concrete containing pineapple leaf fibre (PALF). IOP Conf Ser Mater Sci Eng. 2021; 1200(1):12006. https://doi.org/10.1088/1757-899x/1200/1/012006
5. Adamu M, Labib W, Ibrahim YE, Alanazi H. Mechanical behaviour and durability performance of concrete reinforced with hybrid date palm and polypropylene polymer fibres. Polymers. 2025; 17(10):1350. https://doi.org/10.3390/polym17101350
6. Tetteh AR, Liang Y. Repair of cracks on concrete structures. Int J Sci Res. 2020; 9(4):82. https://doi.org/10.21275/sr20324212517
7. Park B, Choi YC. Self-healing products of cement pastes with supplementary cementitious materials, calcium sulfoaluminate and crystalline admixtures. Materials. 2021; 14(23):7201. https://doi.org/10.3390/ma14237201
8. Tong ZN. To explore the causes and preventive measures of floor cracks. Appl Mech Mater. 2014; 292. https://doi.org/10.4028/www.scientific.net/amm.638-640.292
9. Fu C, Gao Z, Yan P. Nonlinear steel strains in cracked RC beams based on bond-stress profiles. Mater Struct. 2022; 55(8). https://doi.org/10.1617/s11527-022-02048-x
10. Wang Y, Kong X, Fang Q, Chen L, Fan J. Modelling damage mechanisms of concrete under high confinement pressure. Int J Impact Eng. 2021; 150:103815. https://doi.org/10.1016/j.ijimpeng.2021.103815
11. Mussabayev TT, Nuguzhinov Z, Nemova D, Kayupov T, Tolkynbaev TA, Akmakanova AZ, Khafizova GS. Creep of concrete in shell structures: nonlinear theory. Materials. 2023; 16(16):5587. https://doi.org/10.3390/ma16165587
12. Liu S, Pan Y, Li H, Xian G. Durability of the bond between CFRP and concrete exposed to thermal cycles. Materials. 2019; 12(3):515. https://doi.org/10.3390/ma12030515
13. Gopu GN, Joseph SA. Corrosion behavior of fibre-reinforced concrete - a review. Fibres. 2022; 10(5):38. https://doi.org/10.3390/fib10050038
14. Chong FY, An YN, Wang P. Research on factors affecting reinforced concrete durability. Adv Mater Res. 2014; 898:403. https://doi.org/10.4028/www.scientific.net/amr.898.403
15. Asaad MA, Huseien GF, Baghban MH, Raja PB, Федюк P, Faridmehr I, Alrshoudi F. Gum arabic nanoparticles as green corrosion inhibitor for reinforced concrete exposed to carbon dioxide environment. Materials. 2021; 14(24):7867. https://doi.org/10.3390/ma14247867
16. Trofimov BY, Mahmudov A. The structure and properties of hardened cement paste with modifiers. IOP Conf Ser Mater Sci Eng. 2020; 962(2):022011. https://doi.org/10.1088/1757-899x/962/2/022011
17. Tang S, Yao Y, Perdrix CA, Li Z. Recent durability studies on concrete structure. Cem Concr Res. 2015; 78:143. https://doi.org/10.1016/j.cemconres.2015.05.021
18. Turatsinze A, Garros M. On the modulus of elasticity and strain capacity of self-compacting concrete incorporating rubber aggregates. Resour Conserv Recycl. 2008; 52(10):1209. https://doi.org/10.1016/j.resconrec.2008.06.012
19. Rusnak CR. Sustainable strategies for concrete infrastructure preservation: a comprehensive review and perspective. Infrastructures. 2025; 10(4):99. https://doi.org/10.3390/infrastructures10040099
20. Haruna SI. Experimental study on the rate of absorption of water of basalt, polypropylene, and steel fibres reinforced concrete. Stavební obzor. 2021; 30(2). https://doi.org/10.14311/cej.2021.02.0036
21. Chemrouk M, Attari NE. Durability of concrete with particular reference to high performance concrete. In: Recent Advances in Concrete Technology. 2003; 245. https://doi.org/10.1680/rocisd.32477.0024
22. Li Z. The future and development trends of concrete. In: Advanced Concrete Technology. 2011; 476. https://doi.org/10.1002/9780470950067.ch9
23. Jonkers HM, Thijssen AP, Muyzer G, Çopuroğlu O, Schlangen E. Application of bacteria as self-healing agent for the development of sustainable concrete. Ecol Eng. 2009; 36(2):230. https://doi.org/10.1016/j.ecoleng.2008.12.036
24. Hooda Y, Singh HD. Rheodynamic concrete as a progressive viability in the field of concrete technology. Int J Eng Adv Technol. 2020; 9(3):319. https://doi.org/10.35940/ijeat.b3798.029320
25. Jonkers HM. Bacteria-based self-healing concrete. Heron. 2011;56(1/2):1. Available from: http://heronjournal.nl/56-12/1.pdf
26. Lv L, Guo P, Liu G, Han N, Xing F. Light induced self-healing in concrete using novel cementitious capsules containing UV curable adhesive. Cem Concr Compos. 2019; 105:103445. https://doi.org/10.1016/j.cemconcomp.2019.103445

27. Khaloo A, Darabad YP. Investigation of flexural capacity of concrete containing liquid silicone rubber. Shock Vib. 2021; 2021(1). https://doi.org/10.1155/2021/6668283
28. Bansal S, Tamang RK, Bansal P, Bhurtel P. Biological methods to achieve self-healing in concrete. In: Lecture Notes in Civil Engineering. 2019; 63. https://doi.org/10.1007/978-981-13-7615-3_5
29. Gore KB, Chidambararaj N, Kartheesan L, Ghamande MV, Sarode GC. Smart water management in agriculture: enhancing crop productivity with restricted Boltzmann machine. In: 2024 First International Conference on Software, Systems and Information Technology (SSITCON). IEEE; 2024. p. 1-6. https://doi.org/10.1109/SSITCON62437.2024.10796681
30. Madhukar SR, Singh K, Kanniyappan SP, Krishnan T, Sarode GC, Suganthi D. Towards efficient energy management of smart buildings: a LSTM-AE based model. In: 2024 International Conference on Electronics, Computing, Communication and Control Technology (ICECCC). IEEE; 2024. p. 1-6. https://doi.org/10.1109/ICECCC61767.2024.10593988
31. Sarode GC, Chaudhari RS, Siraskar G, Ahire H, Pawar S, Shinde N, Dhore PB, Sarode DG. Assessment of bitumen paver and HMP efficiency for a road project. PanAm Math J. 2024; 34(3):168-76. https://doi.org/10.52783/pmj.v34.i3.1783
32. Chaudhari RS, Siraskar G, Sarode GC, Shirode UR, Warke P, Shinde N. Navigating escalation patterns in road construction projects in Maharashtra. PanAm Math J. 2024; 34(4):586-96. https://doi.org/10.52783/pmj.v34.i4.2027
33. Yadav RS, Nimbalkar A, Gadekar T, Patil P, Patil VN, Gholap AB, Kurhade AS, Dhumal JR, Waware SY. Comparison of experimental and numerical investigation of mono-composite and metal leaf spring. J Mines Met Fuels. 2024; 72(8):815-27. https://doi.org/10.18311/jmmf/2024/45325
34. Yadav RS, Gadekar T, Gundage V, Patil P, Patil A, Patil P, Patil A, Sutar R, Kurhade AS. Numerical and experimental investigation of the effect of overlapping angle on strength and deformation of curved plate joined using arc welding process. J Mines Met Fuels. 2024; 72(10):1059-66. https://doi.org/10.18311/jmmf/2024/45697
35. Yadav RS, Gandhi P, Veeranjaneyulu K, Gaji R, Kirpekar S, Pawar D, Khairnar YS, Patil S, Kurhade AS, Patil SP. Influence of plate thickness on the mechanical behaviour of mild steel curved plates: an experimental study. J Mines Met Fuels. 2024; 72(12):1319-27. https://doi.org/10.18311/jmmf/2024/46253
36. Yadav R, Nimbalkar A, Kirpekar S, Patil PJ, Dalvi SA, Jadhav PA, Kurhade AS, Wakchaure GN. Effect of transformed-induced plasticity steel plate thickness on the ultimate tensile strength of the butt welded joint using Nd: YAG laser. Int J Veh Struct Syst. 2024; 16(6):857-62. https://doi.org/10.4273/ijvss.16.6.08
37. Chougule SM, Murali G, Kurhade AS. Dynamic simulation and performance evaluation of vibratory bowl feeders integrated with paddle shaft mechanisms. Adv Sci Technol Res J. 2025; 19(62). https://doi.org/10.12913/22998624/203873