

Experimental Investigation on Structural Performance of High-Strength M90 Concrete Beams Incorporating Supplementary Cementitious Materials and Steel Fibers

Ashta Priyatharshini G

Post Graduate Student, Coimbatore Institute of Technology,
Coimbatore-641014, Tamil Nadu, India

M. P Muthuraj

Associate Professor, Department of Civil Engineering,
Coimbatore Institute of Technology, Coimbatore - 641014,
Tamil Nadu, India

ABSTRACT - The increasing demand for high-performance construction materials has led to the development of high-strength concrete with improved mechanical and structural properties. This study focuses on the development of M90 high-strength concrete using supplementary cementitious materials (SCMs) such as fly ash, ground granulated blast furnace slag (GGBS), micro silica, quartz sand, and quartz powder. Steel fibres of two different sizes (30 mm × 0.6 mm and 60 mm × 0.75 mm) were incorporated to enhance ductility and crack resistance. A conventional M30 concrete mix was used as a control mix to evaluate the structural performance of the developed M90 concrete. Experimental investigations included compressive strength testing and cyclic loading tests on reinforced concrete beams and frames. The results indicated that the first crack load increased from 17 kN in M30 beams to 50 kN in M90 beams, with improved crack distribution and reduced crack width due to the presence of steel fibres. The M90 concrete exhibited enhanced flexural performance and energy dissipation under cyclic loading, indicating its potential suitability for seismic-resistant structural applications.

KEYWORDS - High Strength Concrete, M90 Concrete, Supplementary Cementitious Materials, Steel Fibre Reinforced concrete, Load-Deflection Behaviour, Energy Dissipation, Ductility, Sustainable Construction.

2. INTRODUCTION

Concrete is one of the most widely used construction materials due to its versatility, durability, and economic advantages. However, conventional concrete mixtures often have limitations in terms of strength, durability, and environmental sustainability. With the rapid development of modern infrastructure, there is an increasing demand for **high-strength and high performance concrete** capable of supporting larger loads while maintaining long-term durability. High-strength concrete provides several advantages including:

- Higher load-carrying capacity
- Reduced structural member size
- Improved durability
- Enhanced resistance to environmental deterioration

In recent years, the incorporation of **supplementary cementitious materials (SCMs)** such as fly ash and ground granulated blast furnace slag (GGBS) has gained considerable attention in concrete technology. These materials improve the microstructure of concrete through pozzolanic reactions, resulting in increased strength and durability. Furthermore, the inclusion of **steel fibres** in concrete enhances tensile strength, crack resistance, and energy absorption capacity. Steel fibres bridge microcracks and delay crack propagation, thereby improving ductility and structural performance. Despite numerous studies on high-strength concrete materials, limited experimental investigations have focused on the **structural performance of reinforced concrete beams made with M90 concrete incorporating SCMs and steel fibres**. Therefore, this study aims to experimentally evaluate the mechanical properties and structural behaviour of reinforced concrete beams made with M90 high-strength concrete and compare their performance with conventional M30 concrete beams.

3. MATERIALS USED

The materials used in this study include cement, fine aggregate, coarse aggregate, supplementary cementitious materials, steel fibres, and water. Ordinary Portland Cement was used as the primary binding material. Natural river sand was used as fine aggregate, and crushed stone aggregates were used as coarse aggregates. To enhance the strength and durability of the high-strength concrete mix, **supplementary cementitious materials such as fly ash and ground granulated blast furnace slag (GGBS)** were incorporated. Hooked-end steel fibres were used to improve tensile strength and crack resistance. Two types of steel fibres were used: **30 mm length × 0.6 mm diameter hooked steel fibres (1.6%) and 60 mm length × 0.75 mm diameter hooked steel fibres (1.6%)**

These fibres help improve crack control and enhance the energy absorption capacity of concrete.

TABLE 1 – MATERIAL PROPERTIES

S.NO	MATERIALS	SPECIFIC GRAVITY
1	Cement	3.15
2	Micro Silica	2.4
3	Fly Ash	2.2
4	GGBS	2.65
5	Quartz Powder	2.63
6	Quartz Sand	2.67
7	Coarse Aggregate 6mm	2.68
8	Coarse Aggregate 12mm	2.87
9	Fine Aggregate (M-sand)	2.82
10	Water	1
11	Steel Fiber 30mmLx0.60mm diameter hooked	7.85
12	Steel Fiber 60mmLx0.75mm diameter hooked	7.85
13	Super plasticizer	1.1

4. MIX PROPORTION AND TRIAL MIXES

Concrete mixes were prepared for **M30 and M90 grades**. The M30 mix was prepared as a conventional concrete mix without the addition of supplementary cementitious materials. For the M90 mix, several trial mixes were prepared using SCMs in order to achieve the required compressive strength. Four trial mixes were produced and tested to determine the optimum mix capable of achieving the target strength.

TABLE 2 – TRIAL MIX- 1 PROPORTIONS FOR M90 CONCRETE

Material	Specific Gravity	Trial Mix 1		
		kg/m3	Percentage	Quantity required for test specimens kg
Cement	3.15	700	28.1%	18.21
Micro Silica	2.4	80	3.2%	2.08
Fly Ash	2.2	80	3.2%	2.08
GGBS	2.65	150	6.0%	3.09
Quartz Powder	2.63	250	10%	6.51
Quartz Sand	2.67	0	0%	0
Coarse Aggregate 20mm	2.68	0	0%	0
Coarse Aggregate 6mm	2.87	350	14%	9.11
Coarse Aggregate 12mm	2.87	150	4%	3.90
Fine Aggregate (M-sand)	2.82	670	10.7%	17.43
Water	1	175	6.0%	4.55
Steel Fiber 30mmLx0.6mm diameter hooked	7.85	40	1.6%	1.04
Super plasticizer	1.1	11.7	0.5%	0.30
Total		2506.7	100%	155.07

TABLE 3 – TRIAL MIX- 2 PROPORTIONS FOR M90 CONCRETE

Material	Specific Gravity	Trial mix 2		
		kg/m3	Percentage	Quantity required for test specimens kg
Cement	3.15	700	27.6%	39.60
Micro Silica	2.4	80	3.2%	4.53
Fly Ash	2.2	80	3.2%	4.53
GGBS	2.65	150	5.9%	8.49
Quartz Powder	2.63	250	9.9%	14.14
Quartz Sand	2.67	460	18.2%	26.02
Coarse Aggregate 6mm	2.87	350	13.8%	19.80
Coarse Aggregate 12mm	2.87	0	0.0%	0.00
Fine Aggregate (M-sand)	2.82	235	9.3%	13.29
Water	1	175	6.9%	9.90
Steel Fiber 30mmLx0.6mm diameter hooked	7.85	40	1.6%	2.26
Super plasticizer	1.1	12	0.5%	0.68
Total		2532	100%	143.24

TABLE 4 – TRIAL MIX- 3 PROPORTIONS FOR M90 CONCRETE

Material	Specific Gravity	Trial Mix 3		
		kg/m3	Percentage	Quantity required for test specimens kg
Cement	3.15	450	16.9%	11.17
Micro Silica	2.4	100	3.2%	4.93
Fly Ash	2.2	280	3.2%	4.93
GGBS	2.65	170	11.8%	18.50
Quartz Powder	2.63	250	7.9%	12.34
Quartz Sand	2.67	350	13.8%	21.59
Coarse Aggregate 6mm	2.87	350	13.8%	21.59
Coarse Aggregate 12mm	2.87	0	0.0%	0.00
Fine Aggregate (M-sand)	2.82	270	10.7%	16.65
Water	1	150	5.9%	9.25
Steel Fiber 60mmLx0.75mm diameter hooked	7.85	40	1.6%	2.47
Super plasticizer	1.1	12	0.5%	0.74
Total		2702	100%	70.31

TABLE 5– TRIAL MIX- 4 PROPORTIONS FOR M90 CONCRETE

Material	Specific Gravity	Trial Mix 4		
		kg/m3	Percentage	Quantity required for test specimens kg
Cement	3.15	550	20.03%	11.17
Micro Silica	2.4	120	3.2%	4.93
Fly Ash	2.2	120	3.2%	4.93
GGBS	2.65	210	11.8%	18.50
Quartz Powder	2.63	450	7.9%	12.34
Quartz Sand	2.67	500	13.8%	21.59
Coarse Aggregate 6mm	2.87	350	13.8%	21.59
Coarse Aggregate 12mm	2.87	0	0.0%	0.00
Fine Aggregate (M-sand)	2.82	270	10.7%	16.65
Water	1	150	5.9%	9.25
Steel Fiber 60mmLx0.75mm diameter hooked	7.85	40	1.6%	2.47
Super plasticizer	1.1	12	0.5%	0.74
Total		2702	100%	70.31

5. EXPERIMENTAL PROGRAM

5.1 COMPRESSIVE STRENGTH TEST

Cube specimens were cast for both M30 and M90 mixes and tested for compressive strength at **7 days and 28 days** using a compression testing machine. The test specimens consisted of **150 mm × 150 mm × 150 mm concrete cubes** prepared according to standard procedures. The cubes were cast in steel moulds, compacted properly to eliminate air voids, and cured in water for **28 days** under controlled laboratory conditions.

TABLE 6 – COMPRESSIVE STRENGTH RESULTS

S.NO	SPECIMEN	7 TH DAY COMPRESSIVE STRENGTH AVERAGE VALUE	28 TH DAY COMPRESSIVE STRENGTH AVERAGE VALUE
1	CUBE (M30)	21.5 MPa	32.1 MPa
2	CUBE (M90-T1)	52.8 MPa	85.2 MPa
3	CUBE (M90-T2)	59.5 MPa	98.62 MPa
4	CUBE (M90-T3)	52.6 MPa	85.96 MPa
5	CUBE (M90-T4)	50.59 MPa	84.26 MPa

The results show that **Trial Mix 2 achieved the highest compressive strength of 98.62 MPa** and therefore this mix was selected for further structural testing.

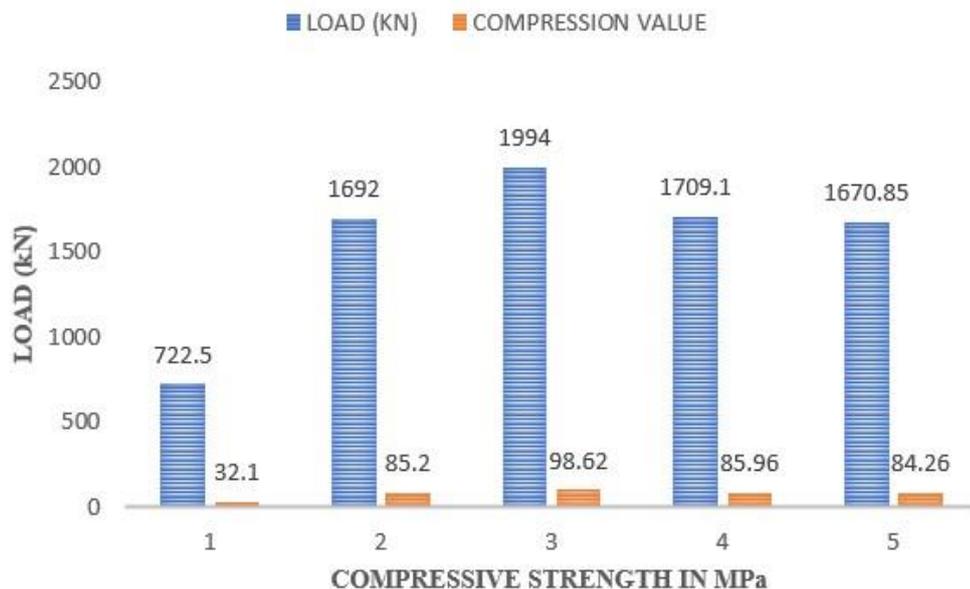


FIGURE 1 – COMPRESSIVE STRENGTH COMPARISON GRAPH

5.2 SPLIT TENSILE STRENGTH TEST

Split tensile strength tests were performed on cylindrical specimens to determine the tensile properties of the concrete mixes. The test was carried out using **cylindrical specimens of size 150 mm diameter and 300 mm height**, prepared and cured in the same manner as the compressive strength specimens. The test was performed using a **Compression Testing Machine**, where the cylinder was placed horizontally between the loading platens. A uniform compressive load was applied along the length of the specimen

until failure occurred. The applied load induced tensile stresses perpendicular to the loading direction, resulting in a splitting failure along the vertical diameter of the cylinder.

TABLE 7 – SPLIT TENSILE STRENGTH RESULTS

S.NO	SPECIMEN	7 TH DAY SPLIT TENSILE STRENGTH AVERAGE VALUE	28 TH DAY SPLIT TENSILE STRENGTH AVERAGE VALUE
1	CYLINDER (M30)	2.54MPa	3.79MPa
2	CYLINDER (M90-T1)	6.40MPa	8.55MPa
3	CYLINDER (M90-T2)	4.60MPa	8.80MPa
4	CYLINDER (M90-T3)	6.35MPa	8.48MPa
5	CYLINDER (M90-T4)	6.55MPa	8.72MPa



FIGURE 2 – SPLIT TENSILE STRENGTH COMPARISON

6. BEAM SPECIMEN DETAILS

Reinforced concrete beams were cast using the optimized M90 mix and conventional M30 mix. **Reinforcement details:** Top reinforcement: **2 bars of 8 mm diameter**, Bottom reinforcement: **2 bars of 10 mm diameter**, **Stirrups:** First L/3 region → **75 mm spacing**, Middle L/3 region → **100 mm spacing**. Beam specimens were tested using **two-point loading** condition.

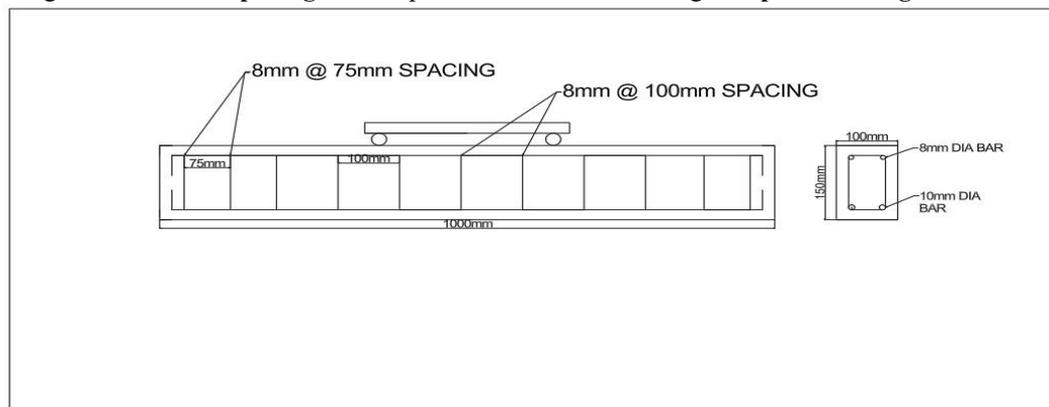


FIGURE 3 - BEAM REINFORCEMENT DIAGRAM
7. RESULTS AND DISCUSSION

7.1 LOAD-DEFLECTION BEHAVIOUR

The load-deflection curves obtained from the experimental testing illustrate the structural response of the beam specimens. The M30 beam exhibited an ultimate load capacity of 45 kN, while the M90 beam reached 75 kN. This represents approximately **66% higher load-carrying capacity** for the M90 beam.

DEFLECTION (mm) M90	LOAD (KN)	DEFLECTION (mm) M30
0	0	0
0.09	2.5	0.05
0.15	5	0.12
0.25	7.5	0.21
0.32	10	0.3
0.45	12.5	0.38
0.54	15	0.48
0.67	17.5	0.59
0.76	20	1.05
0.86	22.5	1.46
0.98	25	1.76
1.02	27.5	2.03
1.1	30	2.46
1.56	32.5	2.84
1.86	35	3.25
2.3	37.5	3.59
2.85	40	3.9
3.15	42.5	
3.59	45	
3.85	47.5	
4.02	50	
4.34	52.5	
4.89	55	
5.21	57.5	
5.68	60	
5.98	62.5	
6.25	65	
6.78	67.5	
7.15	70	
7.86	72.5	
8.15	75	

TABLE 8 – LOAD VS DEFLECTION

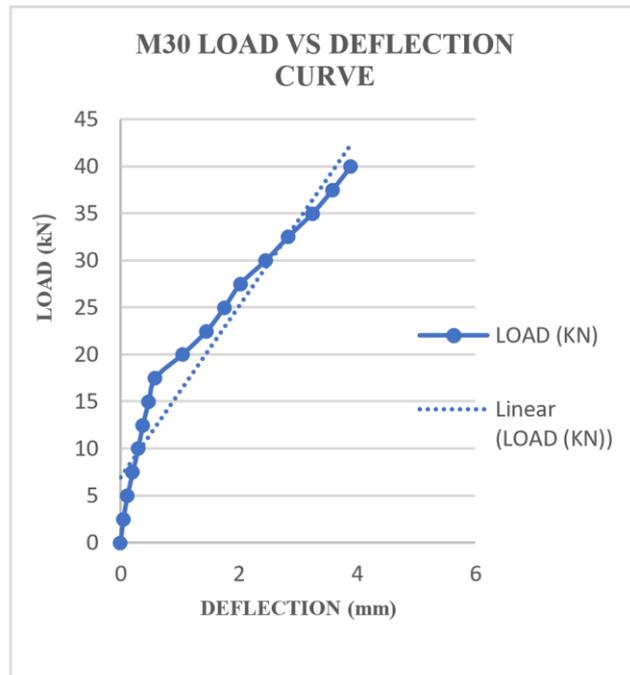


FIGURE 4 - M30 DEFLECTION GRAPH

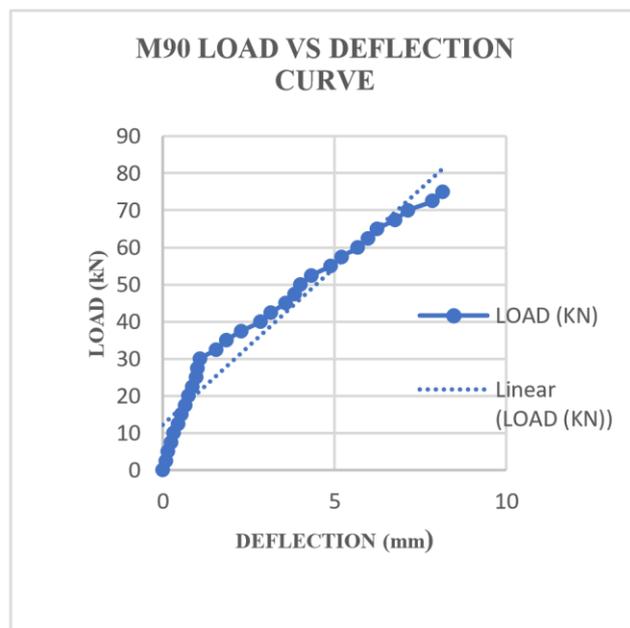


FIGURE 5 - M90 DEFLECTION GRAPH

7.2 ENERGY DISSIPATION

The M90 beam exhibited significantly higher energy dissipation capacity compared to the M30 beam. This improvement can be attributed to the presence of steel fibres, which enhance crack bridging and delay crack propagation.

LOAD (KN)	DEFLECTION (mm) M90	CUMULATIVE ENERGY (KN-mm) M90	DEFLECTION (mm) M30	CUMULATIVE ENERGY (KN-mm) M30
0	0	0	0	0
2.5	0.09	0.1125	0.05	0.0625
5	0.15	0.225	0.12	0.325
7.5	0.25	0.625	0.21	0.8875
10	0.32	0.6125	0.3	1.675
12.5	0.45	1.4625	0.38	2.575
15	0.54	1.2375	0.48	3.95
17.5	0.67	2.1125	0.59	5.7375
20	0.76	1.687	1.05	14.3625
22.5	0.86	2.125	1.46	23.0875
25	0.98	2.85	1.76	30.2125
27.5	1.02	1.05	2.03	37.3
30	1.1	2.3	2.46	49.6625
32.5	1.56	14.375	2.84	61.5375
35	1.86	10.125	3.25	75.375
37.5	2.3	15.95	3.59	87.7
40	2.85	21.3125	3.9	99.7125
42.5	3.15	12.375		
45	3.59	19.25		
47.5	3.85	12.025		
50	4.02	8.287		
52.5	4.34	16.4		
55	4.89	29.5625		
57.5	5.21	18		
60	5.68	27.6125		
62.5	5.98	18.375		
65	6.25	17.2125		
67.5	6.78	35.1125		
70	7.15	25.4375		
72.5	7.86	50.5875		
75	8.15	21.3875		

TABLE 9 – DEFLECTION VS CUMULATIVE ENERGY GRAPH

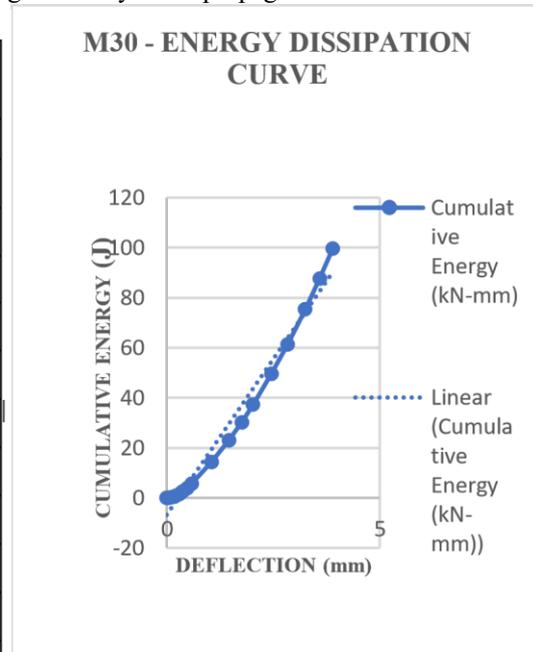


FIGURE 6 – M30 CUMULATIVE ENERGY GRAPH

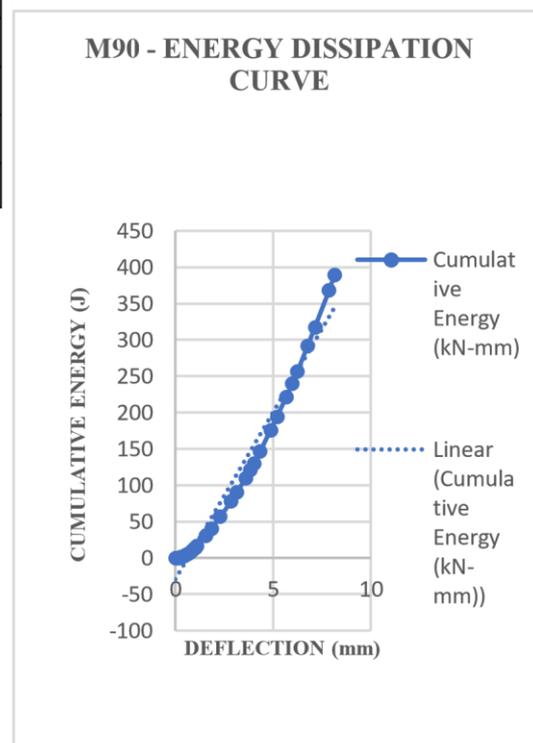


FIGURE 7 – M90 CUMULATIVE ENERGY GRAPH

7.3 DUCTILITY BEHAVIOUR

The ductility ratio of the M90 beam was higher than that of the conventional M30 beam, indicating improved deformation capacity before failure.

LOAD (KN)	DUCTILITY (μ) M90	DUCTILITY (μ) M30
0	0	0
2.5	0.017822	0.020325
5	0.029703	0.04878
7.5	0.049505	0.085366
10	0.063366	0.121951
12.5	0.089109	0.154472
15	0.106931	0.195122
17.5	0.132673	0.239837
20	0.150495	0.426829
22.5	0.170297	0.593496
25	0.194059	0.715447
27.5	0.20198	0.825203
30	0.217822	1
32.5	0.308911	1.154472
35	0.368317	1.321138
37.5	0.455446	1.45935
40	0.564356	1.585366
42.5	0.623762	
45	0.710891	
47.5	0.762376	
50	0.79604	
52.5	0.859406	
55	0.968317	
57.5	1.031683	
60	1.124752	
62.5	1.184158	
65	1.237624	
67.5	1.342574	
70	1.415842	
72.5	1.556436	
75	1.613861	

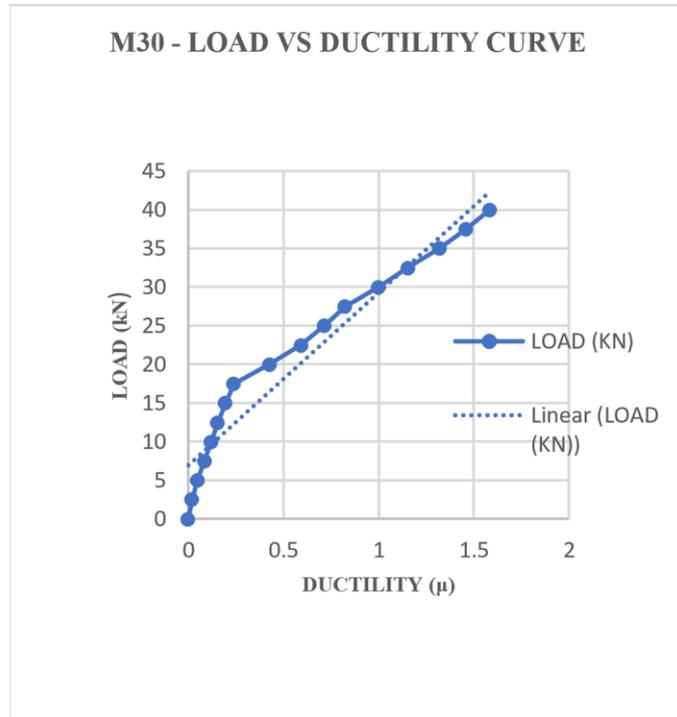


FIGURE 8 – M30 DUCTILITY GRAPH

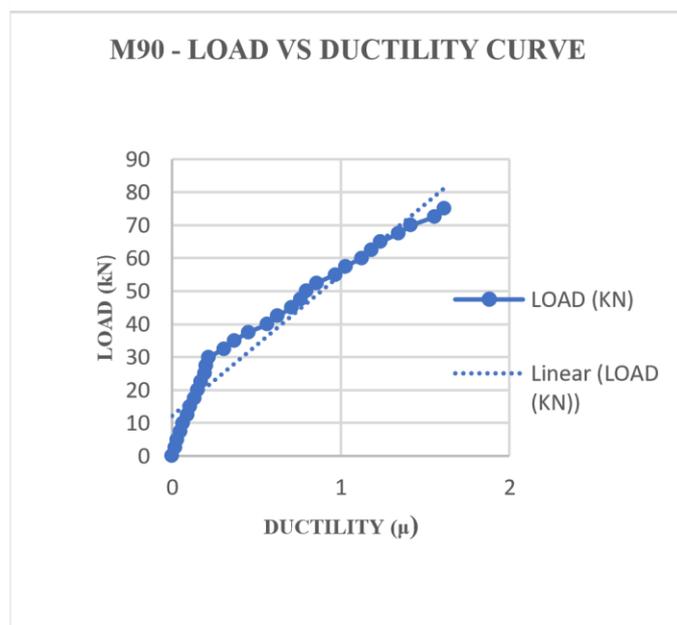


FIGURE 9 –M90 DUCTILITY GRAPH

TABLE 10 – LOAD VS DUCTILITY

7.4 CRACK PATTERN AND FAILURE MODE

The M30 beam exhibited limited cracks followed by sudden shear failure. The M90 beam showed **multiple distributed cracks**, indicating improved crack control due to steel fibre reinforcement. Although both beams ultimately failed in shear, the M90 beam sustained significantly higher loads before failure.

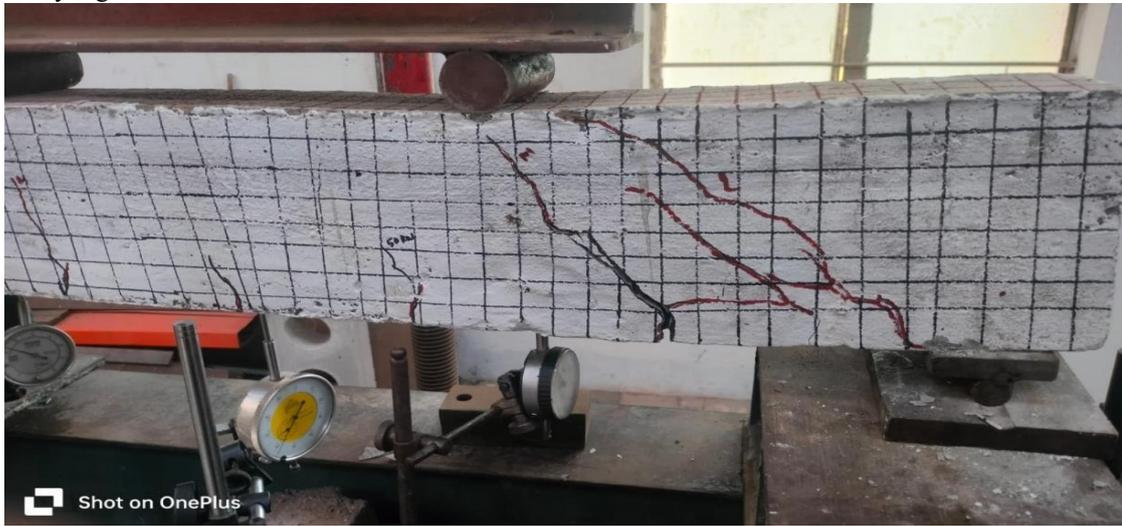


FIGURE 10 - M30 BEAM FAILURE



FIGURE 11 - M90 BEAM FAILURE

8. STRUCTURAL PERFORMANCE SUMMARY

PARAMETER	M30 BEAM	M90 BEAM
Compression test	32.1 MPa	98.62MPa
Split-Tensile test	3.79 MPa	8.80MPa
Ultimate Load	45KN	75KN
Failure Mode	Shear	Shear
Crack Pattern	Limited	Distributed

TABLE 11 – STRUCTURAL PERFORMANCE

9. CONCLUSION

The experimental investigation evaluated the mechanical and structural performance of reinforced concrete beams made with high-strength M90 concrete incorporating supplementary cementitious materials and steel fibres. The optimized M90 mix achieved a compressive strength of **98.62 MPa**, significantly higher than the **32.1 MPa** obtained for conventional M30 concrete. Similarly, the split tensile strength of the M90 mix reached **8.80 MPa**, compared to **3.79 MPa** for M30 concrete. Beam testing results indicated that the M90 beam achieved an ultimate load of **75 kN**, whereas the M30 beam failed at **45 kN**, representing approximately **66% improvement in load-carrying capacity**. The M90 beam also demonstrated improved crack distribution, higher energy dissipation, and enhanced ductility. The results confirm that SCM-based high-strength concrete reinforced with steel fibres can significantly enhance structural performance while contributing to sustainable construction practices.

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