Educational Administration: Theory and Practice
2024, 30(4), 4232-4248
ISSN: 2148-2403
https://kuey.net/
Research Article

Performance Analysis Of Expanded Clay And Polypropylene Fibre-Based Lightweight Structural Concrete Beams

Abhijit Babar[1*], C. P. Pise[2], S. G. Rathod[3]

[1*]PG Student, Department of Civil Engineering S.K.N Sinhgad College of Engineering Pandharpur. Email- abhijitbabar86@gmail.com
[2]Associate Professor, Department of Civil Engineering S.K.N Sinhgad College of Engineering Pandharpur
[3]Assistant Professor, Department of Civil Engineering S.K.N Sinhgad College of Engineering Pandharpur

Citation: Abhijit Babar et al. (2024) Performance Analysis Of Expanded Clay And Polypropylene Fibre-Based Lightweight Structural Concrete Beams, *Educational Administration: Theory and Practice*, *3*(4), 4232-4248
Doi: 10.53555/kuey.v30i4.2176

ARTICLE INFO	ABSTRACT

This study focuses on structural lightweight concrete (SLWC) beams reinforced with polypropylene fiber (PP) and expanded clay particles. The PP fiber volume percentage is the primary topic of this study. We employed volume fractions of 0.1%, 0.2%, 0.3%, and 0.4% for the PP fibers in the study. We experimented with various ECA replacement dosages to achieve the optimal balance of workability and strength. The optimal quantity of ECA to replace, according to the studies, is 20%. The mechanical, microstructural, and durability aspects of the specimens should be examined. The specimens should have dimensions of 150 x 150 x 150 mm, 150 x 300 mm, 100 x 100 x 500 mm, and 100 x 50 mm, respectively. We measured the moduli of rupture and modulus of elasticity for control and structural lightweight concrete, both with and without PP fibers. We used these tests to assess the water absorption, porosity, sorptivity, and acid resistance of control concrete, structural lightweight concrete with and without PP fibers, and specimens sized 150 x 150 x 150 mm cube and 100 x 50 mm disc. This study focuses on lightweight structural concrete beams reinforced using expanded clay aggregates (ECA) and polypropylene fibers. To determine if these novel composite beams are sustainable, we will examine their mechanical, thermal, and durability properties. The experimental program creates lightweight concrete beams by adjusting the quantities of expanding clay particles and polypropylene fibers. Standardized testing evaluates mechanical parameters such as compressive strength, flexural strength, and modulus of elasticity. We also consider the heat insulation and thermal conductivity of composite beams for green buildings. Researchers test lightweight concrete beams to ensure that they can survive freeze-thaw cycles and chloride ion penetration. We look at how expanded clay particles, polypropylene fibers, and the cementitious matrix stick together by using scanning electron microscopy and X-ray powder diffraction. This study investigates the use of expanded clay and polypropylene fibers in lightweight concrete technology to improve structural performance while reducing material density. Overall, this research supports green and efficient building practices by emphasizing the need to adopt lightweight materials with increased mechanical qualities in building structures.

1. Introduction

More stringent requirements for the longevity, security, and ecological friendliness of buildings, as well as their economic viability and energy efficiency, are hallmarks of modern building practices [1–5]. Reinforced concrete, polymer concrete, fiber-reinforced concrete, and concrete are among the many types of structures that rely on concrete as a base, and the material accounts for the vast majority of construction industry usage [6–10]. Optimal efficiency in the construction of building components and structures requires special attention to technological, constructive, and installation approaches. Simultaneously, the need to construct buildings in challenging environments is a major challenge with modern construction in many regions. The maximum practicable decrease in weight in engineering structures is, hence, an important condition for guaranteeing the quality and safety of construction [11]. Reducing the weight of construction materials, components, and buildings while maintaining or improving their quality is an important objective for the building industry [12]. Due to the great need for lightweight and cellular concrete, research and development efforts are underway worldwide in this area. Nowadays, modern construction and science have figured out how to alter the building formation and properties of lightweight and cellular concretes using recipe-technological methods [13]. As a result, these materials are used for both enclosing and load-bearing structures. Among the many varieties of concrete, lightweight concrete with porous particles is among the most common, significant, and well-liked. The conditional average density of these concretes varies between 800 and 2000–2200 kg/m3. Porous aggregates, either mixed in throughout the cement-sand matrix or used in place of some of the natural aggregate, allow for a wide density range to be achieved. Lightweight concrete's density is defined by the proportion of porous to natural aggregate. The next sections address the difficulties of optimizing specific compositions and provide creative answers one by one. The need for integrated construction and environmental solutions for the utilization of different forms of waste in construction [14–18] is the problematization of this study, and the environmental aspect reflects that. Identifying the optimal location for applicable trash in concrete is the technical challenge of the project.It is not uncommon for such waste to serve as both a filler and a partial binder substitute. But pay close attention to the third quality: constructiveness. Reinforcement features like concrete are helpful in and of themselves, but when it comes to dispersion, a particular kind of reinforcement, there's a complex factor that affects design, technology, and recipes all at once. Scattered fiber reinforcement of concrete using so-called fibers from different sources is the definition of this solution. Several problems are fully addressed when we include the environmental aspect, namely when we look at the possibility of using fibers made from various forms of waste [19–21].

2. Lightweight Structural Concrete Beams Made Of Expanded Clay And Polypropylene Fibres

The unique use of expanded clay and polypropylene fibers in lightweight structural concrete beams combines the structural performance of concrete with the advantages of decreased weight and durability. This article describes these composite beams' main components and properties: ECA: Expanded clay aggregates Properties: Natural clay-derived expanded clay aggregates are lightweight, porous, and granular. They expand at high temperatures, creating a porous, low-density structure. ECA is popular in building materials because of its thermal insulation characteristics. Low density reduces structural weight, which is important in weight-sensitive applications. Polypropylene Fibers: high-tensile, flexible synthetic fibers. They strengthen concrete, making it stronger and more crack-resistant. Advantages: Polypropylene fibers improve concrete ductility and durability. It reduces cracking, particularly in stress zones, enhancing material performance and lifetime. Lightweight Concrete Beam Synergy: Polypropylene fibers and expanded clay particles combine to maximize their strengths. Expanded clay offers lightweight and thermal insulation, while polypropylene fibers increase flexural strength and fracture resistance. The synergy balances weight reduction and structural robustness to overcome lightweight concrete's constraints. Mechanical Qualities: The performance assessment tests the concrete beams' compressive strength to verify they fulfill structural application criteria. Flexural Strength: Beams must endure bending pressures for structural integrity, and polypropylene fibers usually improve this. Thermal Characteristics: Due to its lightweight nature, expanded clay insulates against heat conductivity. Applications that need thermal efficiency benefit from this. Durability factors: Freeze-Thaw Resistance: Lightweight concrete beams are tested for freeze-thaw resistance to ensure their acceptability at different temperatures. Chloride Ion Penetration: For coastal or deicing salt-exposed structures, chloride ion penetration is tested to measure corrosion resistance. Microstructural Analysis: SEM and XRD may be used to investigate the lightweight concrete's microstructure to reveal component interfacial bonding. Environmental Sustainability: Lightweight materials reduce transportation and manufacturing carbon emissions, supporting worldwide efforts to promote green building. In conclusion, lightweight structural concrete beams constructed of expanded clay and polypropylene fibers provide a sustainable building option with decreased weight, better mechanical qualities, and increased durability. This study seeks to improve our knowledge and use of composite materials in diverse structural situations.

2.1 Advantages and Disadvantages of lightweight structural concrete beams made of expanded clay and polypropylene fibers:

The performance evaluation of lightweight structural concrete beams made of expanded clay and polypropylene fibers offers several advantages, contributing to the advancement of sustainable and efficient construction practices. Some key advantages include:

Weight Reduction:

1. Enhanced Mechanical Properties:
2. Improved Thermal Insulation:
3. Durability and Crack Resistance:
4. Sustainability and Environmental Impact:
5. Versatility in Applications:
6. Reduced Construction Costs:
7. Innovative Construction Practices:

8. Resistance to Environmental Factors:
9. Microstructural Insights:

3. Results and Discussion

3.1 Influence PP Fibres on Compressive strength

Table 1 compares the compressive strengths of cubes and cylinders with and without expanded clay aggregate and polypropylene fibers. Expanded clay-based structural lightweight concrete samples with and without polypropylene fibers demonstrated a significantly higher average compressive strength than control concrete. Compressive strength increased by 3.77% and 10.40% with 0.1% and 0.2% polypropylene fiber volume fractions, respectively. Compressive strength increased to 28.22 N/m2 in concrete with 0.3% polypropylene fibers. The PPP fibers and matrix may bind strongly, strengthening cubes. Concrete with 0.4% volume-percentage polypropylene fibers has reduced compressive strength. This fiber content's decreased compressive strength may be due to concrete fiber spreading issues (Jianming Gao et al.). Figs. 1 and 2 show an increase in the compressive strength percentages of cubes and cylinders.

Table 1 Concrete Specimens' Compressive Strength

Sr. No	Designation	Aggregate Content of Expanded Clay (%)	Polypropylene Fibre (%)	Cube Compressive Strength (MPa)	Cylinder Compressive Strength (MPa)
1	CC	20	0	33.33	26.71
2	EC0	20	0	23.55	18.84
3	EC1	20	0.1	24.44	19.58
4	EC2	20	0.2	26.00	20.94
5	EC3	20	0.3	28.22	22.64
6	EC4	20	0.4	25.42	20.37

3.2 Failure modes

Fig. 3 shows polypropylene fiber-based lightweight concrete cube failure patterns with expanded clay aggregate. Early cracks were surface-only. Cracks propagated within cube specimens as axial tension increased. This period also saw concrete spalling. Polypropylene fibers modify cube failure patterns. The modified polypropylene fibers slowed down crack propagation. The polypropylene fibers within concrete contain it, avoiding cracking and spalling. The cube specimen failure pattern is greatly affected by polypropylene fiber volume.

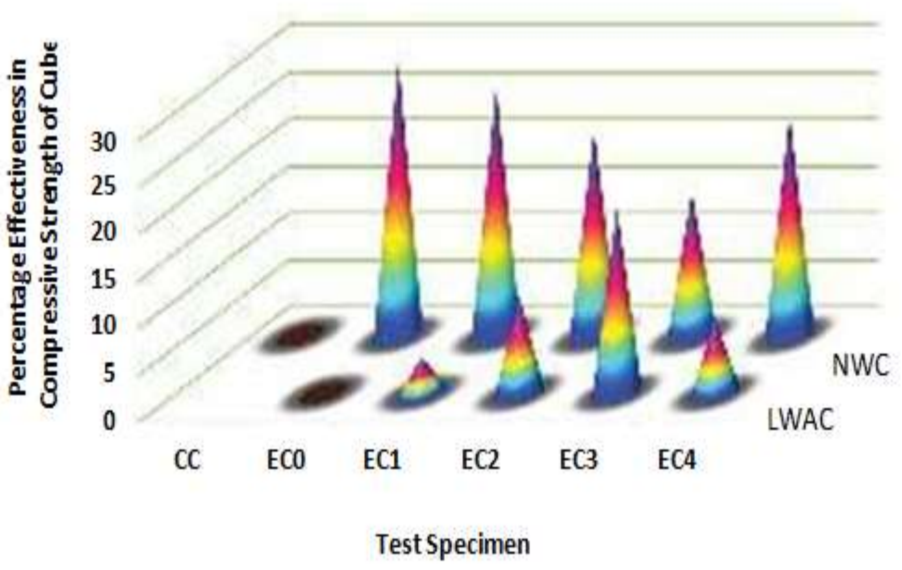

Fig. 1 Effect of PP Fibres Cube Compressive Strength

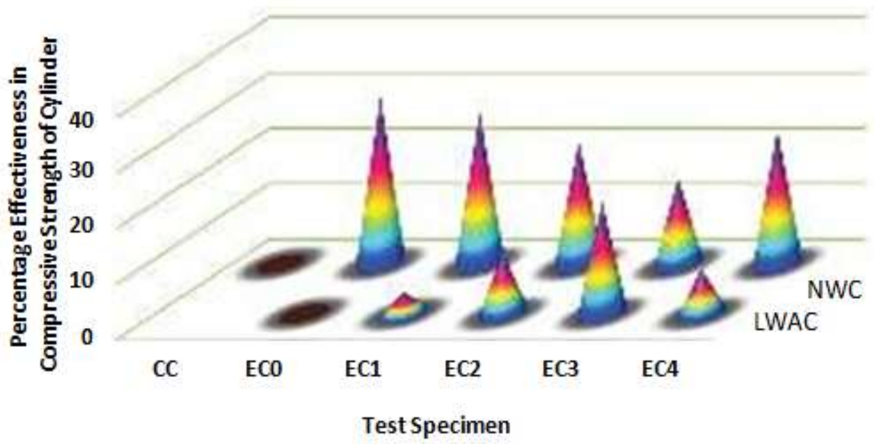

Fig. 2 Effect of PP Fibres Cylinder Compressive Strength

Fig. 3 Failure Pattern of Cube specimens

Table 2 Modulus of Rupture of Concrete Specimens

Sl.No	Designation	Expanded Clay Aggregate Content (%)	Polypropylene Fibre (%)	Modulus of Rupture (MPa)
1	CC	20	0	6.5
2	EC0	20	0	4.7
3	EC1	20	0.1	5.2
4	EC2	20	0.2	5.8
5	EC3	20	0.3	6.5
6	EC4	20	0.4	7.4

Table 3 Modulus of Elasticity of Concrete Specimens

Sl.No	Designation	Expanded Clay Aggregate Content (%)	Polypropylene Fibre (%)	Modulus of Elasticity (GPa)
1	CC	20	0	28.21
2	EC0	20	0	24.39
3	EC1	20	0.1	24.60
4	EC2	20	0.2	25.50
5	EC3	20	0.3	26.87
6	EC4	20	0.4	27.26

3.3 Failure modes

We compressed the cylinder specimens using a 2000 kN machine. Fig. 4 shows polypropylene fiber-based lightweight concrete cylinder specimen failure patterns with expanded clay aggregate. The cylindrical specimen has a large macrobreak throughout its height early on. The specimen surface developed longitudinal fissures with increasing axial compressive stress. Polypropylene filaments alter cylinder failure patterns. retarded crack propagation. Crack density increased. Concrete didn't fracture or spall because polypropylene fibers contained it. Polypropylene fiber volume percentage strongly influences cylinder failure patterns.

Fig.4 Failure Pattern of Cylinder Specimens

3.4 DURABILITY PROPERTIES

Table 4 Water Absorption of Concrete Specimens

Sl. No	Designation	Expanded Clay Aggregate Content (%)	Polypropylene Fibre (%)	Percentage of Water Absorption
1	CC	20	0	0.46
2	EC0	20	0	0.65
3	EC1	20	0.1	0.61
4	EC2	20	0.2	0.47
5	EC3	20	0.3	0.39
6	EC4	20	0.4	0.44

Table 5 Porosity of Concrete Specimens

Sl.No	Designation	Expanded Clay Aggregate Content (%)	Polypropylene Fibre (%)	Saturated Water Absorption	Volume of Permeable voids (%)
1	CC	20	0	0.65	1.01
2	EC0	20	0	0.83	1.45
3	EC1	20	0.1	0.61	1.21
4	EC2	20	0.2	0.47	0.95
5	EC3	20	0.3	0.37	0.75
6	EC4	20	0.4	0.45	0.92

3.5 Influence of PP Fibres on Sorptivity

Hardened concrete has sorbent capability through capillary rising. Concrete porosity determines sorptivity. PP fibers of 0.1%, 0.2%, and 0.3% volume percent decrease sorptivity. Sorptivity decreased due to fiber bridging. Bundling increased porosity with a 0.4% volume percentage of PP fibers. Water absorption over time is seen in Fig. 5.

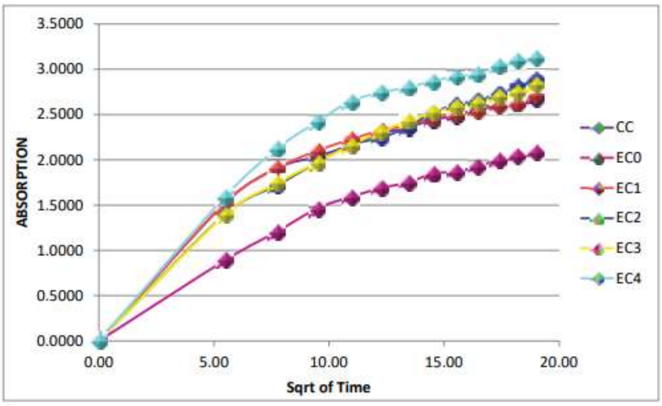

Fig. 5 Water Absorption Vs Time

3.6 Influence of PP Fibres on Acid Resistance

Table 4.6 shows the weight and strength loss of structural lightweight concrete with polypropylene fibers. Compared to control concrete, structurally lightweight concrete with 0% fiber lost weight and strength faster. Weight and strength loss decreased with 0.1%, 0.2%, and 0.3% fiber volume fractions. Uniform fiber distribution may reduce voids. Concrete with a 0.4% volume percentage of fibers lost weight and strength somewhat. Fiber balling may cause this. Figs. 4.20 and 4.21 demonstrate how PP fibers affect weight and strength loss.

Table 6 Acid Resistance of Concrete Specimens

Sl.No	Designation	Expanded Clay Aggregate Content (%)	Polypropylene Fibre (%)	Percentage of Weight Loss	Percentageof StrengthLoss
1	CC	20	0	5.10	1.55
2	EC0	20	0	5.44	1.0
3	EC1	20	0.1	4.32	1.5
4	EC2	20	0.2	4.10	1.45
5	EC3	20	0.3	3.44	1.17
6	EC4	20	0.4	3.99	1.53

3.7 Static Response Of Beam Specimens

The results of static test carried out on six beams are presented in this chapter. Out of the six beams, one beam was made out of control concrete, one beam was made out of ECA based structural lightweight concrete and four beams were made out of were ECA based structural lightweight concrete with polypropylene fibres. Under monotonic loading, all beams failed. We studied the first crack load, yield load, ultimate load, deflection ductility, energy ductility, and energy ductility ratio. Load against center span deflection and moment versus curvature of beam specimens indicate the effect of polypropylene fiber volume percentage and lightweight expanded clay aggregate on flexural performance.

Table 7 Test Results on Strength of Beam Specimens

Designation	First Crack Stage	Yield Stage	Ultimate Stage
	Load (kN)	Load (kN)	Load (kN)
CBS	15.00	31.45	55.00
ECS0	13.5	29.32	50.25
ECS1	14.75	30.90	52.50
ECS2	16.50	34.75	55.75
ECS3	18.75	35.60	60.00
ECS4	20.25	38.60	65.25

Table 8 Test Results on Deformation of Beam Specimens

Designation	First Crack Stage	Yield Stage	Ultimate Stage
	Deflection(mm)	Deflection(mm)	Deflection(mm)
CBS	1.52	3.98	11.77
ECS0	1.85	4.52	14.47
ECS1	2.42	4.87	16.32
ECS2	2.65	4.93	17.80
ECS3	3.11	5.02	18.87
ECS4	3.77	5.13	19.95

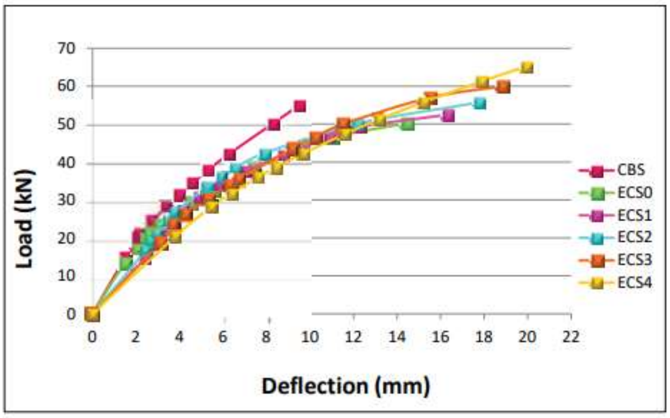

Fig.6. Load Vs. Deflection Relationship

3.8 Moment Vs. Curvature Relationship

Fig. 4.29 shows all tested beam moment-curvature graphs. Up to the first crack stage, M-Phi curves were linear with steeper slopes. As time passed, the curve slope decreased. This pattern persisted until yield. Beyond yield, the curve slope decreased. Up to the last step, beam curvature increased with smaller moment increments. Further momentary increases crushed the concrete in the compression zone and failed the beams.

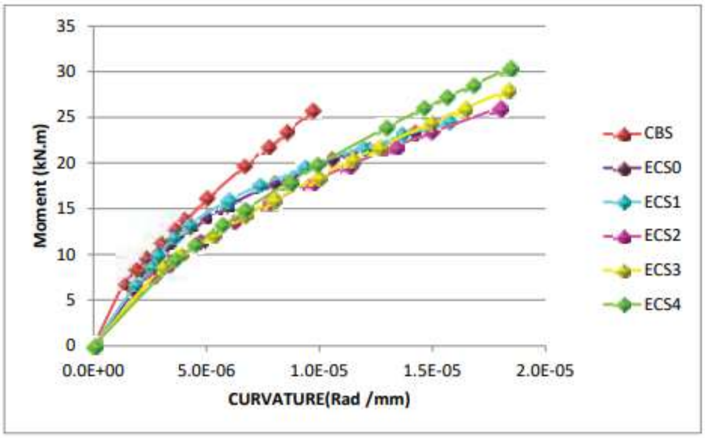

Fig.7. Moment Vs Curvature Relationship

Influence of PP Fibres on Crack Patterns and Failure modes

Table 4.9 shows the failure crack pattern, breadth, and quantity for all tested beams. Initial loading caused fine vertical fractures in the moment zone. The existing vertical fractures progressed towards the compression zone, and new fine vertical cracks formed along the loaded span with increasing stress. Cracks grew in number and breadth with loads until the final stage. The addition of PP fibers causes more fractures that are approaching collapse.

Table 9 Cracking History and Mode of Failure

Designation	Width of Crack(millimeter)	Number of Cracks	Cracks Spacing (millimeter)	Failure Mode
CBS	0.57	17	152	Flexure
ECS0	0.61	18	140	
ECS1	0.55	19	123	
ECS2	0.53	20	110	
ECS3	0.49	23	94	
ECS4	0.45	26	82	

Compared to the CBC beam, ECS1, ECS2, ECS3, and ECS4 decreased 4.35%, 8.7%, 17.39%, and 26.09%, respectively. Beam ECS0 increased 8.70% over the CBS beam. Compared to ECS0, crack width decreased by 12%, 16%, 24%, and 32% in beams ECS1, ECS2, ECS3, and ECS4. Beam ECS4 had 22.73%, 19.05%, and 10.53% less fracture width than beams ECS1, ECS2, and ECS3. Beam ECS3 has 13.64% and 9.52% less fracture width than beams ECS1 and ECS2. Beam ECS2 has 4.55% less fracture width than beam ECS1. Crack width reduction percentage is shown in Fig. 4.30.Compared to the CBC beam, ECS0, ECS1, ECS2, ECS3, and ECS4 increased 6.67%, 13.33%, 20.00%, 40.00%, and 60.00%, respectively. ECS1, ECS2, ECS3, and ECS4 have 6.25%, 12.5%, 31.25%, and 50% more cracks than ECS0. Beam ECS4 had 41.18%, 33.33%, and 14.29% more cracks than beams ECS1, ECS2, and ECS3. Beam ECS3 has 23.53% and 16.67% more cracks than beams ECS1 and ECS2. Beam ECS2 has 5.88% more fractures than beam ECS1. Fig. 4.31 shows crack growth. Compared to the CBC beam, ECS0, ECS1, ECS2, ECS3, and ECS4 decreased 8.57%, 20.71%, 30.00%, 41.43%, and 50.00%, respectively. Compared to reference beam ECS0, beams ECS1, ECS2, ECS3, and ECS4 have 13.28%, 23.44%, 35.94%, and 45.31% less crack spacing. Compared to beams ECS1, ECS2, and ECS3, beam ECS4 had 36.94%, 28.57%, and 14.63% less crack spacing. Compared to beams ECS1 and ECS2, beam ECS3 had 26.13% and 16.33% less crack spacing, respectively. Crack spacing decreased by 11.71% in beam ECS2 versus beam ECS1. Crack spacing reduction percentage is seen in Fig. 4.32.

Fig.7. Crack Pattern of Beam

Table.10 Ductility Indices of Beam Specimens

Sl. No	Beam Designation	Deflection Ductility	Deflection Ductility Ratio	Energy Ductility	Energy DuctilityRatio	Curvature ductility	Curvature Ductility Ratio
1	CBS	2.96	1	6.37	1	2.96	1
2	ECS0	3.2	1.08	6.15	0.97	3.2	1.08
3	ECS1	3.35	1.13	6.45	1.01	3.35	1.13
4	ECS2	3.61	1.22	6.81	1.07	3.61	1.22
5	ECS3	3.76	1.27	7.32	1.15	3.76	1.27
6	ECS4	3.89	1.31	7.95	1.25	3.89	1.31

Table 11 Energy Capacity of Tested Beams

Sl. No	Designation	Energy Capacity(kN-mm)
1	CBS	443.13
2	ECS0	404.14
3	ECS1	432.86
4	ECS2	677.43
5	ECS3	762.25
6	ECS4	797.25

The energy capacity has been calculated as Total area under load vs deflection plot upto ultimate load.

3.9 Cyclic Response Of Beam Specimens

Six recycled beams were used until they failed. Sufficient data was collected for the following parameters in both the control and lightweight aggregate concrete beams reinforced with polypropylene fibers: total energy absorption, failure mechanism, crack diameter, crack number, fracture spacing, deflection, and stiffness (K). This part presents and discusses the results of the study objectives. The beam cyclic test results are shown in Table 4.12.

Table 12 Test Results at Ultimate stage

Beam Designation	Number of Cycles	Deflection (mm)	Stiffness (kN/mm)	Crack Width (mm)	Number of Cracks	Spacingof Cracks (mm)	Total Energy Absorption (kN-mm)
CBC	10	20	2.256	0.28	10	124	693.00
ECC0	8	16	2.361	0.30	13	106	463.49
ECC1	9	18	2.223	0.30	14	95	598.13
ECC2	10	20	2.156	0.32	16	89	739.49
ECC3	11	22	1.964	0.34	19	80	934.95
ECC4	12	24	1.850	0.36	22	69	1035.45

Table 13 Cyclic Test Results of CBC Beam

No. of Cycles	Deflection (mm)	Stiffness (kN/mm)	Crack Width (mm)	No. of Cracks	Spacing of Cracks (mm)	Total Energy Absorption (kN-mm)
1	2	6.860	0.15	6	138	17.82
2	4	6.020	0.16	6	137	50.34
3	6	5.240	0.17	7	135	76.23
4	8	4.580	0.18	8	133	142.56
5	10	4.130	0.21	8	133	207.9
6	12	3.854	0.24	9	132	280.5
7	14	3.230	0.25	10	129	356.4
8	16	2.684	0.26	10	128	486.44
9	18	2.456	0.27	10	127	577.5
10	20	2.256	0.28	10	124	693.00

3.10 Cyclic Response of ECCO Beam

Table 4.14 shows the ECC0 beam test results. ECC0's structurally lightweight concrete beam survived eight cycles. The maximum beam deflection was 16mm. The beam absorbed 463.49 kN/mm of energy throughout the cycle test. The resulting beam stiffness was 2.36 kN/mm. The average crack spacing was 106 mm, with 13 recorded. The crack width was 0.3mm. Figs. 4.47–4.50 illustrate cyclic load vs. deflection, stiffness vs. cracks, deflection vs. cycles, and energy absorption vs. cycles.In the second cycle, deflection was 4mm, stiffness was 5.56 kN/mm, and crack width was 0.15 mm. Seven cracks were found in this condition. The average crack spacing for this condition was 143. We absorbed 30.65 kN/mm of energy in this scenario. In the fourth cycle, deflection was 8mm, stiffness was 4.23 kN/mm, and crack width was 0.18 mm. Nine cracks were found in this condition. The average crack spacing for this condition was 137. 118.31 kN/mm of energy was absorbed in this scenario.Deflection was 12mm, stiffness was 3.26 kN/mm, and crack width was 0.24 mm in the sixth cycle. Ten cracks were found in this condition. The average crack spacing for this condition was 122. In this situation, 247.15 kN/mm of energy was absorbed.During cycle 8, deflection was 16mm, stiffness was 2.36 kN/mm, and crack width was 0.3mm. 13 cracks were found in this condition. The average crack spacing for this condition was 106. In this situation, 463.49 kN/mm of energy was absorbed.

Table 14 Cyclic Test Results of ECCO Beam

No. ofCycles	Deflection(mm)	Stiffness (kN/mm)	CrackWidth(mm)	No. of Cracks	Spacingof Cracks(mm)	Total Energy Absorption(kN-mm)
1	2	6.53	0.14	7	144	11.88
2	4	5.56	0.15	7	143	30.65
3	6	5.06	0.17	9	137	53.14
4	8	4.23	0.18	9	137	118.31
5	10	3.85	0.21	9	136	176.32
6	12	3.26	0.24	10	122	247.15
7	14	2.76	0.28	11	113	306.39
8	16	2.36	0.3	13	106	463.49

4. Comparison of ECCO beam with CBC beam

At the second cycle, ECC0 beam stiffness reduced by 5.05% and crack width fell by 7.14% compared to CBC beam. Cracks in this condition rose to 14.29%. Crack spacing dropped to 4.17% at this level. Energy absorption rose to 64.241% in this circumstance.At cycle four, ECC0 beam stiffness fell 8.27% and crack width reduced 11.11% compared to CBC beam. Cracks in this condition rose to 11.11%. Crack spacing dropped to 2.92% at this level. Energy absorption rose to 20.497% in this circumstance.At cycle six, ECC0 beam rigidity reduced to 18.22% and crack width decreased by 4.00% compared to CBC beam. Cracks for this ailment rose to 10%. Crack spacing dropped to 8.19% at this level. Energy absorption rose to 13.49% in this circumstance.

At cycle 8, ECC0 beam stiffness reduced to 13.68% and crack width decreased by 13.33% compared to CBC beam. Cracks for this condition rose to 23.07%. Crack spacing dropped to 20.75% at this level. Energy absorption rose to 4.95% in this scenario.

4.1 Cyclic Response of ECC1 Beam

- Table 4.15 shows the ECC1 beam test results. The ECC1 structural lightweight concrete beam with polypropylene fibers survived nine cycles. The maximum beam deflection was 18mm. The beam absorbed 598.13 kN/mm of energy throughout the cycle test. The resulting beam rigidity was 2.22 kN/mm. They found 14 cracks with an average spacing of 95 mm. The crack width was 0.3mm. Figs. 4.51–4.54 illustrate cyclic load vs. deflection, stiffness vs. cracks, deflection vs. cycles, and energy absorption vs. cycles.
- In the second cycle, deflection was 4mm, stiffness was 5.73 kN/mm, and crack width was 0.14 mm. Nine cracks were found in this condition. The average crack spacing for this condition was 146. We absorbed 42.51 kN/mm of energy in this scenario.
- In the fourth cycle, deflection was 8mm, stiffness was 4.36 kN/mm, and crack width was 0.19 mm. Ten cracks were found in this condition. The average crack spacing for this disease was 135. 129.32 kN/mm of energy was absorbed in this scenario.
- In the sixth cycle, deflection was 12mm, stiffness was 3.62 kN/mm, and crack width was 0.25 mm. Ten cracks were found in this condition. The average crack spacing for this condition was 134. In this situation, 261.32 kN/mm of energy was absorbed.
- Eighth cycle deflection was 16mm, stiffness was 2.56 kN/mm, and crack width was 0.29mm. Twelve cracks were found in this condition. The average crack spacing for this condition was 105. In this situation, 472.23 kN/mm of energy was absorbed.
- In the ninth cycle, deflection was 18mm, stiffness was 2.22 kN/mm, and crack width was 0.3mm. 14 cracks were found in this condition. The average crack spacing for this disease was 95. We absorbed 598.13 kN/mm of energy in this scenario.

Table 15 Cyclic Test Results of ECC1 Beam

No. of Cycles	Deflection(mm)	Stiffness (kN/mm)	Crack Width (mm)	No. of Cracks	Spacingof Cracks (mm)	Total Energy Absorption (kN-mm)
1	2	6.71	0.13	9	147	14.03
2	4	5.73	0.14	9	146	42.51
3	6	5.14	0.16	9	146	68.68
4	8	4.36	0.19	10	135	129.32
5	10	3.99	0.22	10	134	235.95
6	12	3.62	0.25	10	134	261.32
7	14	2.85	0.26	10	133	324.33
8	16	2.56	0.29	12	105	472.23
9	18	2.22	0.3	14	95	598.13

4.2 Comparison of ECC1 beam with CBC beam

- ECC1 beam stiffness was reduced by 4.36% and crack width decreased by 14.28% in the second cycle compared to the CBC beam. Cracks in this condition rose to 33.33%. Average crack spacing dropped to 6.16%

at this level. Energy absorption rose to 18.41% in this circumstance.

- At the fourth cycle, ECC1 beam stiffness fell to 5.05% and crack width was reduced by 5.26% compared to the CBC beam. Cracks in this state rose to 20%. Crack spacing dropped to 1.48% at this level. Energy absorption rose to 10.23% in this scenario.
- At the sixth cycle, ECC1 beam rigidity reduced to 6.46% and crack width decreased by 4% compared to CBC beam. Cracks for this ailment rose to 10%. Crack spacing dropped to 1.49% at this level. Energy absorption rose to 7.33% in this circumstance.
- ECC1 beam stiffness dropped to 4.84%, and crack width decreased by 10.34% at the eighth cycle compared to the CBC beam. Cracks in this condition rose to 16.67%. The average crack spacing dropped to 21.90%. Energy absorption rose to 3.09% in this circumstance.
- ECC1 beam stiffness dropped to 10.48%, and crack width decreased by 10% at the ninth cycle compared to the CBC beam. Cracks in this condition rose to 28.57%. Crack spacing dropped to 33.68% at this level. Energy absorption rose to 3.44% in this circumstance.

4.3 Comparison of ECC1 beam with ECCO beam

- When comparing the ECC1 beam to the ECC0 beam at the second cycle, stiffness rose by 2.96% and crack width was reduced by 7.14%. Cracks for this condition rose to 22.22%. Crack spacing dropped to 2.05% at this level. Energy absorption rose to 27.89% in this circumstance.
- The ECC1 beam stiffened by 2.98% and the crack width was reduced by 5.26% at the fourth cycle compared to the ECC0 beam. Cracks for this ailment rose to 10%. Crack spacing dropped to 1.48% at this level. Energy absorption rose to 8.51% in this circumstance.
- Compared to the ECC0 beam at the sixth cycle, the ECC1 beam rigidity rose to 9.94%, and crack width was reduced by 4%. Cracks for this ailment rose to 10%. Crack spacing dropped to 8.95% at this level. Energy absorption rose to 5.42% in this circumstance.
- Between the ECC1 and ECC0 beams during the eighth cycle, stiffness rose to 7.77% and crack width was reduced by 3.45%. Cracks in this condition rose to 8.33%. Crack spacing averaged 0.95% at this level. Energy absorption rose to 1.85% in this scenario.

4.4 Cyclic Response of ECC2 Beam

Table 4.16 displays the ECC2 beam test results. ECC2, a structural lightweight concrete beam with polypropylene fibers, survived ten cycles. The maximum beam deflection was 20mm. The beam absorbed 739.20 kN/mm of energy throughout the cycle test. The resulting beam rigidity was 2.16 kN/mm. There were 16 cracks, with an average spacing of 89 mm. The fissures were 0.32 mm wide. Figs. 4.55–4.58 show plots for cyclic load vs. deflection, stiffness vs. cracks, deflection vs. cycles, and energy absorption vs. cycles.

- In the second cycle, deflection was 4mm, stiffness was 6.03 kN/mm, and crack width was 0.16 mm. Nine cracks were found in this condition. The average crack spacing for this condition was 150. We absorbed 72.36 kN/mm of energy in this scenario.
- In the fourth cycle, deflection was 8mm, stiffness was 4.96 kN/mm, and crack width was 0.20 mm. Eleven cracks were found in this condition. The average crack spacing for this condition was 139.165. 31 kN/mm of energy was absorbed in this scenario.
- In the sixth cycle, deflection was 12mm, stiffness was 3.95 kN/mm, and crack width was 0.26 mm. 14 cracks were found in this condition. The average crack spacing for this disease was 130. In this situation, 300.21 kN/mm of energy was absorbed.
- Eighth cycle: 16mm deflection, 2.75 kN/mm stiffness, 0.30 mm crack width. 15 cracks were found in this condition. The average crack spacing for this condition was 124. In this situation, 590.12 kN/mm of energy was absorbed.
- In the tenth cycle, deflection was 18mm, stiffness was 2.16 kN/mm, and crack width was 0.32mm. 16 cracks were found in this condition. The average crack spacing for this condition was 89. We absorbed 739.2 kN/mm of energy in this scenario.

Table 16 Cyclic Test Results of ECC2 Beam

No. ofCycles	Deflection(mm)	Stiffness(kN/mm)	Crack Width (mm)	No. of Cracks	Spacing of Cracks (mm)	Total Energy Absorption (kN-mm)
1	2	7.53	0.12	9	151	21.36
2	4	6.03	0.16	9	150	72.36
3	6	5.56	0.14	11	139	102.63
4	8	4.96	0.20	11	139	165.31
5	10	4.37	0.24	14	131	261.85
6	12	3.95	0.26	14	130	300.21
7	14	3.53	0.27	15	124	456.35
8	16	2.75	0.30	15	124	590.12
9	18	2.36	0.31	15	123	634.79
10	20	2.16	0.32	16	89	739.2

4.5 Comparison of ECC2 beam with CBC beam

- At the second cycle, ECC2 beam stiffness reduced to 0.83% and crack width decreased by 23% compared to CBC beam. Cracks in this condition rose to 33.33%. Crack spacing dropped to 8.67% at this level. Energy absorption rose to 30.43% in this circumstance.
- At the fourth cycle, ECC2 beam stiffness fell 7.66% and crack width reduced 4.76% compared to CBC beam. Cracks for this disease rose to 27.27%. Average crack spacing dropped to 4.32% at this level. Energy absorption rose to 13.76% in this circumstance.
- At the sixth cycle, ECC2 beam rigidity reduced to 2.43% and crack width decreased by 7.69% compared to CBC beam. Cracks for this ailment rose to 35.71%. Crack spacing dropped to 1.54% at this level. Energy absorption rose to 6.56% in this circumstance.
- At the eighth cycle, ECC2 beam stiffness reduced to 2.4% and crack width decreased by 13.33% compared to the CBC beam. Cracks in this condition rose to 33.33%. Crack spacing dropped to 3.24% at this level. Energy absorption rose to 17.56% in this circumstance.
- At the ninth cycle, ECC2 beam rigidity reduced to 4.64% and crack width decreased by 12.5% compared to CBC beam. Cracks in this disease rose to 37.5%. The average crack spacing dropped to 39.32%. Energy absorption rose to 6.25% in this circumstance.

4.6 Comparison of ECC2 beam with ECCO beam

- ECC2 beam rigidity increased 7.79% and crack width reduced 15.38% in the second cycle compared to the ECC0 beam. Cracks for this condition rose to 22.22%. Average crack spacing dropped to 4.6% at this level. Energy absorption rose to 57.64% in this circumstance.
- ECC2 beam rigidity rose to 14.71% and crack width was reduced by 10% at the fourth cycle compared to the ECC0 beam. Cracks for this ailment rose to 18.18 percent. Crack spacing dropped to 1.43% at this level. Energy absorption rose to 28.43% in this circumstance.
- ECC2 beam rigidity increased 17.47% and crack width reduced 7.69% in the sixth cycle compared to the ECC0 beam. Cracks in this condition rose to 28.57%. Average crack spacing dropped to 6.15% at this level. Energy absorption rose to 17.67% in this circumstance.
- ECC2 beam rigidity rose to 14.15% and crack width was reduced by 3.23% at the eighth cycle compared to the ECC0 beam. Cracks in this condition rose to 13.33%. Crack spacing dropped to 14.52% at this level. Energy absorption rose to 21.46% in this circumstance.

4.7 Comparison of ECC2 beam with ECC1 beam

- ECC2 beam rigidity rose to 4.97%, and crack width was reduced by 7.69% in the second cycle compared to the ECC1 beam. Cracks for this ailment rose to 10%. Crack spacing dropped to 2.67% at this level. Energy absorption rose to 41.25% in this circumstance.
- ECC2 beam rigidity rose to 12.09% and crack width was reduced by 5.00% at the fourth cycle compared to the ECC1 beam. Cracks in this condition rose to 9.09%. Crack spacing dropped to 2.87% at this level. Energy absorption rose to 21.77% in this circumstance.
- Comparing the ECC2 beam to the ECC1 beam at cycle 6, stiffness rose to 8.35% and crack width was reduced by 3.85%. Cracks in this condition rose to 28.57%. Crack spacing dropped to 3.08% at this level. Energy absorption rose to 12.95% in this circumstance.
- ECC2 beam rigidity rose to 6.91% and crack width was reduced by 3.33% at the eighth cycle compared to the ECC1 beam. Cracks in this state rose to 20%. Crack spacing dropped to 15.32% at this level. Energy absorption rose to 19.97% in this circumstance.
- ECC2 beam rigidity rose to 5.81% and crack width was reduced by 3.23% in the ninth cycle compared to the ECC1 beam. Cracks in this condition rose to 6.67%. Crack spacing dropped to 22.76% at this level. Energy absorption rose to 5.78% in this circumstance.

4.8 Cyclic Response of ECC3 Beam

ECC3 beam test results are in Table 4.17. The ECC3 structural lightweight concrete beam with polypropylene fibres survived ten cycles. The maximum beam deflection was 22mm. The beam absorbed 934.45 kN/mm of energy throughout the cycle test. The resulting beam stiffness was 1.96 kN/mm. They found 16 cracks with an average spacing of 80 mm. The fissures were 0.34 mm wide. Figs. 4.59–4.62 show cyclic load vs. deflection, stiffness vs. fractures, deflection vs. cycles, and energy absorption vs. cycles.

- In the second cycle, deflection was 4mm, stiffness was 6.98 kN/mm, and crack width was 0.12 mm. Twelve cracks were found in this condition. The average crack spacing for this condition was 125. 89.56 kN/mm of energy was absorbed in this scenario.
- Deflection was 8mm, rigidity was 5.36 kN/mm, and crack width was 0.25 mm in the fourth cycle. 15 cracks were found in this condition. The average crack spacing for this condition was 113. In this situation, 254.18 kN/mm of energy was absorbed.
- In the sixth cycle, deflection was 12mm, stiffness was 4.07 kN/mm, and crack width was 0.27 mm. 15 cracks were found in this condition. The average crack spacing for this condition was 112. In this situation, 38.69

kN/mm of energy was absorbed.

• Eighth cycle: 16mm deflection, 2.86 kN/mm stiffness, 0.31 mm crack width. 16 cracks were found in this condition. The average crack spacing for this disease was 99. In this situation, 664.21 kN/mm of energy was absorbed.

• In the tenth cycle, deflection was 18mm, stiffness was 2.24 kN/mm, and crack width was 0.33mm. 19 cracks were found in this condition. The average crack spacing for this disease was 84. In this situation, 857.45 kN/mm of energy was absorbed.

• In the eleveth cycle, deflection was 18mm, rigidity was 1.96 kN/mm, and crack width was 0.34mm. 19 cracks were found in this condition. The average crack spacing for this condition was 80. In this situation, 934.95 kN/mm of energy was absorbed.

Table 17 Cyclic Test Results of ECC3 Beam

No. of Cycles	Deflection (mm)	Stiffness (kN/mm)	Crack Width (mm)	No. of Cracks	Spacingof Cracks (mm)	Total Energy Absorption (kN-mm)
1	2	8.21	0.11	12	135	30.12
2	4	6.98	0.12	12	125	89.56
3	6	5.84	0.24	13	120	145.96
4	8	5.36	0.25	15	113	254.18
5	10	4.85	0.26	15	113	311.63
6	12	4.07	0.27	15	112	378.69
7	14	3.65	0.28	16	100	596.35
8	16	2.86	0.31	16	99	664.21
9	18	2.57	0.32	17	87	729.55
10	20	2.24	0.33	19	84	857.45
11	22	1.96	0.34	19	80	934.95

4.9 Comparison of ECC3 beam with CBC beam

• In the second cycle, ECC3 beam stiffness fell 14.36% and crack width was reduced by 33.33% compared to the CBC beam. Cracks for this disease rose to 50%. Average crack spacing dropped to 9.6% at this level. Energy absorption rose to 43.91% in this circumstance.

• At the fourth cycle, ECC3 beam rigidity reduced to 14.55% and crack width decreased by 20% compared to CBC beam. Cracks in this condition rose to 46.67%. The average crack spacing dropped to 17.69%. Energy absorption rose to 43.91% in this scenario.

• At the sixth cycle, ECC3 beam rigidity reduced to 5.30% and crack width decreased by 11.11% compared to CBC beam. Cracks in this state rose to 40%. Crack spacing dropped to 17.85% at this level. Energy absorption rose to 25.92% in this circumstance.

• At the eighth cycle, ECC3 beam rigidity was reduced to 6.15% and crack width decreased by 16.13% compared to the CBC beam. Cracks in this disease rose to 37.5%. Crack spacing dropped to 29.29% at this level. Energy absorption rose to 26.76% in this circumstance.

• At the tenth cycle, ECC3 beam stiffness reduced to 0.71% and crack width decreased by 15.15% compared to CBC beam. Cracks in this condition rose to 47.37%. Crack spacing dropped to 47.62% at this level. Energy absorption rose to 19.18% in this circumstance.

4.10 Comparison of ECC3 beam with ECCO beam

- ECC3 beam rigidity rose to 20.34% and crack width reduced by 25% in the second cycle compared to ECC0 beam. Cracks for this condition rose to 41.67%. Crack spacing dropped to 14.4% at this level. Energy absorption rose to 65.77% in this circumstance.
- ECC3 beam rigidity rose to 21.08% and crack width was reduced by 28% at the fourth cycle compared to the ECC0 beam. Cracks in this state rose to 40%. Crack spacing dropped to 21.23% at this level. Energy absorption rose to 53.45% in this circumstance.
- ECC3 beam rigidity rose to 19.90% and crack width reduced by 11.11% in the sixth cycle compared to ECC0 beam. Cracks for this condition rose to 33.33%. Average crack spacing dropped to 8.9% at this level. Energy absorption rose to 34.74% in this circumstance.
- ECC3 beam rigidity rose to 17.45% and crack width was reduced by 3.22% at the eighth cycle compared to the ECC0 beam. Cracks for this disease rose to 18.75%. Crack spacing dropped to 7.07% at this level. Energy absorption rose to 30.22% in this circumstance.

4.11 Comparison of ECC3 beam with ECC1 beam

- Comparing the ECC3 beam to the ECC1 beam at the second cycle, stiffness rose 17.90% and crack width was reduced by 16.67%. Cracks in this state rose to 25%. Crack spacing dropped to 16.8% at this level. Energy absorption rose to 52.53% in this circumstance.
- ECC3 beam rigidity rose to 18.66% and crack width was reduced by 24% at the fourth cycle compared to the ECC1 beam. Cracks in this condition rose to 33.33%. Crack spacing dropped to 19.46% at this level.

Energy absorption rose to 49.12% in this circumstance.

- ECC3 beam rigidity rose to 11.05% and crack width was reduced by 7.41% at the sixth cycle compared to the ECC1 beam. Cracks in this condition rose to 33.33%. Crack spacing dropped to 19.64% at this level. Energy absorption rose to 30.99% in this circumstance.
- ECC3 beam rigidity rose to 10.48% and crack width was reduced by 6.45% at the eighth cycle compared to the ECC1 beam. Cracks in this state rose to 25%. Average crack spacing dropped to 6.06% at this level. Energy absorption rose to 28.90% in this circumstance.
- ECC3 beam rigidity rose to 13.40% and crack width was reduced by 6.25% in the ninth cycle compared to the ECC1 beam. Cracks in this situation rose to 17.65%. Crack spacing dropped to 9.19% at this level. Energy absorption rose to 18.01% in this circumstance.

4.12 Comparison of ECC3 beam with ECC2 beam

- When comparing the ECC3 beam to the ECC2 beam in the second cycle, stiffness rose to 13.61% and crack width was reduced by 8.33%. Cracks in this state rose to 25%. Average crack spacing dropped to 20% at this level. Energy absorption rose to 19.20% in this circumstance.
- ECC3 beam rigidity rose to 7.46% and crack width was reduced by 20% at the fourth cycle compared to the ECC2 beam. Cracks in this condition rose to 26.67%. The average crack spacing dropped to 23.00%. Energy absorption rose to 34.96% in this scenario.
- ECC3 beam rigidity rose to 2.94% and crack width was reduced by 3.7% in the sixth cycle compared to the ECC2 beam. Cracks in this condition rose to 6.67%. Crack spacing dropped to 16.07% at this level. Energy absorption rose to 20.72% in this circumstance.
- ECC3 beam rigidity rose to 3.75% and crack width was reduced by 3.03% at the eighth cycle compared to the ECC2 beam. Cracks for this ailment rose to 6.25 percent. Crack spacing dropped to 25.25% at this level. Energy absorption rose to 11.15% in this circumstance.
- ECC3 beam rigidity rose to 3.75% and crack width was reduced by 3.03% in the tenth cycle compared to the ECC2 beam. Cracks in this condition rose to 15.79%. Crack spacing dropped to 5.95% at this level. Energy absorption rose to 13.79% in this circumstance.

4.13Cyclic Response of ECC4 Beam

ECC4 beam test results are in Table 4.18. The ECC4 structural lightweight concrete beam with polypropylene fibres survived 12 cycles. The maximum beam deflection was 24mm. The beam absorbed 1035.45 kN/mm of energy throughout the cycle test. The resulting beam rigidity was 1.85 kN/mm. There were 22 cracks, with an average spacing of 69 mm. The fissures were 0.36 mm wide. Figs. 4.63 to 4.66 show plots for cyclic load vs. deflection, stiffness vs. cracks, deflection vs. cycles, and energy absorption vs. cycles.

- In the second cycle, deflection was 4 mm, stiffness was 7.26 kN/mm, and crack width was 0.11 mm. 17 cracks were found in this condition. The average crack spacing for this condition was 121. 122.32 kN/mm of energy was absorbed in this scenario.
- Deflection was 8mm, rigidity was 5.75 kN/mm, and crack width was 0.28 mm in the fourth cycle. 17 cracks were found in this condition. The average crack spacing for this condition was 119. In this situation, 345 kN/mm of energy was absorbed.
- Deflection was 12mm, stiffness was 4.65 kN/mm, and crack width was 0.30 mm in the sixth cycle. 19 cracks were found in this condition. The average crack spacing for this condition was 102. In this situation, 498.63 kN/mm of energy was absorbed.
- During cycle 8, deflection was 16mm, stiffness was 3.62 kN/mm, and crack width was 0.32 mm. Twenty cracks were found in this condition. The average crack spacing for this condition was 74. In this situation, 722.66 kN/mm of energy was absorbed.
- In the tenth cycle, deflection was 18mm, stiffness was 2.43 kN/mm, and crack width was 0.34 mm. Twenty cracks were found in this condition. The average crack spacing for this disease was 72. In this situation, 906.31 kN/mm of energy was absorbed.
- During the 12th cycle, deflection was 18mm, stiffness was 1.85 kN/mm, and crack width was 0.36mm. 22 cracks were found in this condition. The average crack spacing for this disease was 69. In this situation, 1035.45 kN/mm of energy was absorbed.

Table 18 Cyclic Test Results of ECC4 Beam

No. of Cycles	Deflection (mm)	Stiffness (kN/mm)	Crack Width(mm)	No. of Cracks	Spacing of Cracks(mm)	Total Energy Absorption(kN.mm)
1	2	8.89	0.10	16	134	45.65
2	4	7.26	0.11	17	121	122.32
3	6	6.14	0.27	17	120	230.33
4	8	5.75	0.28	17	119	345
5	10	5.06	0.29	19	102	404.55
6	12	4.65	0.30	19	102	498.63

7	14	4.16	0.31	19	100	647.96
8	16	3.62	0.32	20	74	722.66
9	18	2.95	0.33	20	73	846.31
10	20	2.43	0.34	20	72	906.31
11	22	2.17	0.35	22	70	985.66
12	24	1.85	0.36	22	69	1035.45

4.14 Comparison of ECC4 beam with CBC beam

- The second cycle rigidity of the ECC4 beam was 17.63% lower than that of the CBC beam, while the crack width was 45.45% lower. Cracks in this condition rose to 64.71%. Crack spacing dropped to 13.22% at this level. Energy absorption rose to 58.85% in this circumstance.
- At cycle four, ECC4 beam rigidity reduced by 20.35% and crack width fell by 28.57% compared to CBC beam. Cracks in this ailment rose to 52.94 percent. Crack spacing dropped to 11.76% at this level. Energy absorption rose to 58.67% in this circumstance.
- ECC4 beam stiffness fell to 17.12% and crack width was reduced by 20% in the sixth cycle compared to the CBC beam. Cracks in this condition rose to 52.63%. Crack spacing dropped to 29.41% at this level. Energy absorption rose to 43.74% in this circumstance.
- At the eighth cycle, ECC4 beam rigidity reduced to 25.85% and crack width decreased 18.75% compared to CBC beam. Cracks in this condition rose to 47.37%. The average crack spacing dropped to 72.97%. Energy absorption rose to 32.69% in this circumstance.
- At the tenth cycle, ECC4 beam stiffness reduced by 7.16% and crack width fell by 17.64% compared to CBC beam. Cracks for this disease rose to 50%. Crack spacing dropped to 72.22% at this level. Energy absorption rose to 23.53% in this circumstance.

4.15 Comparison of ECC4 beam with ECCO beam

- ECC4 beam rigidity increased by 23.42% and crack width was reduced by 36.36% in the second cycle compared to the ECC0 beam. Cracks in this condition rose to 58.82%. Crack spacing dropped to 18.18% at this level. Energy absorption rose to 74.94% in this circumstance.
- ECC4 beam rigidity increased by 26.43% and crack width was reduced by 35.71% at the fourth cycle compared to the ECC0 beam. Cracks for this disease rose to 47.06%. The average crack spacing dropped to 15.13%. Energy absorption rose to 65.70% in this circumstance.
- ECC4 beam rigidity rose to 29.89%, and crack width was reduced by 20% at the sixth cycle compared to the ECC0 beam. Cracks in this condition rose to 47.37%. Crack spacing dropped to 19.61% at this level. Energy absorption rose to 50.43% in this circumstance.
- ECC4 beam rigidity rose to 34.78% and crack width was reduced by 6.25% at the eighth cycle compared to the ECC0 beam. Cracks for this disease rose to 35%. The average crack spacing dropped to 43.24%. Energy absorption rose to 35.86% in this circumstance.

4.16 Comparison of ECC4 beam with ECC1 beam

- Comparing the ECC4 beam to the ECC1 beam at the second cycle, stiffness rose by 21.07% and crack width was reduced by 27.27%. Cracks for this disease rose to 47.06%. Crack spacing dropped to 20.66% at this level. Energy absorption rose to 65.24% in this scenario.
- ECC4 beam rigidity rose to 24.17% and crack width was reduced by 32.14% at the fourth cycle compared to the ECC1 beam. Cracks in this condition rose to 41.18%. Crack spacing dropped to 13.44% at this level. Energy absorption rose to 62.52% in this circumstance.
- ECC4 beam rigidity rose to 22.15% and crack width was reduced by 16.67% at the sixth cycle compared to the ECC1 beam. Cracks in this condition rose to 47.37%. Crack spacing dropped to 31.37% at this level. Energy absorption rose to 47.59% in this circumstance.
- Comparing the ECC4 beam to the ECC1 beam during the eighth cycle, stiffness rose 29.28% and crack width dropped 9.37%. Cracks in this state rose to 40%. Crack spacing dropped to 41.89% at this level. Energy absorption rose to 34.65% in this circumstance.
- ECC4 beam rigidity rose to 24.64%, and crack width was reduced by 9.09% at the ninth cycle compared to the ECC1 beam. Cracks in this state rose to 30%. Crack spacing dropped to 30.13% at this level. Energy absorption rose to 29.32% in this circumstance.

4.17 Comparison of ECC4 beam with ECC2 beam

- ECC4 beam rigidity rose to 16.94% and crack width was reduced by 18.18% in the second cycle compared to the ECC2 beam. Cracks for this disease rose to 47.05%. The average crack spacing dropped to 23.96%. Energy absorption rose to 40.84% in this circumstance.
- ECC4 beam rigidity rose to 13.73% and crack width was reduced by 28.57% in the fourth cycle compared to the ECC2 beam. Cracks in this ailment rose to 35.29 percent. Crack spacing dropped to 16.81% at this level. Under this circumstance, energy absorption rose to 52.08 percent.

- ECC4 beam rigidity rose to 15.05% and crack width was reduced by 13.33% in the sixth cycle compared to the ECC2 beam. Cracks in this condition rose to 26.31%. Crack spacing dropped to 27.45% at this level. Energy absorption rose to 39.79% in this circumstance.
- ECC4 beam rigidity rose to 24.03% and crack width was reduced by 6.25% at the eighth cycle compared to the ECC2 beam. Cracks in this condition rose to 2256.31%. The average crack spacing dropped to 67.57%. Energy absorption rose to 18.34% in this circumstance.
- ECC4 beam rigidity rose to 11.27% and crack width was reduced by 5.88% in the tenth cycle compared to the ECC2 beam. Cracks in this state rose to 20%. Crack spacing dropped to 23.61% at this level. Energy absorption rose to 18.43% in this circumstance.

4.18 Comparison of ECC4 beam with ECC3 beam

- ECC4 beam rigidity rose to 3.86% and crack width was reduced by 9.09% in the second cycle compared to the ECC3 beam. Cracks for this condition rose to 29.41%. Crack spacing dropped to 3.31% at this level. Energy absorption rose to 26.78% in this circumstance.
- ECC4 beam rigidity rose to 6.78% and crack width was reduced by 10.71% in the fourth cycle compared to the ECC3 beam. Cracks in this condition rose to 11.76%. Crack spacing dropped to 5.04% at this level. Under this circumstance, energy absorption rose to 26.32 percent.
- ECC4 beam rigidity rose to 12.47% and crack width was reduced by 10% at the sixth cycle compared to the ECC3 beam. Cracks in this condition rose to 21.05%. Crack spacing dropped to 9.81% at this level. Energy absorption rose to 24.05% in this circumstance.
- ECC4 beam rigidity rose to 20.99% and crack width was reduced by 3.13% at the eighth cycle compared to the ECC3 beam. Cracks in this state rose to 20%. Crack spacing dropped to 33.78% at this level. Energy absorption rose to 8.08% in this circumstance.
- ECC4 beam rigidity rose to 7.82% and crack width reduced by 2.94% in the tenth cycle compared to ECC3 beam. Cracks for this disease rose to 5%. Crack spacing dropped to 16.67% at this level. Energy absorption rose to 5.39% in this circumstance.
- ECC4 beam rigidity rose to 9.49% and crack width was reduced by 2.85% in the eleventh cycle compared to the ECC3 beam. Cracks for this ailment rose to 13.63 percent. Crack spacing dropped to 14.28% at this level. Energy absorption rose to 5.14% in this circumstance.

4.19Failure Mode and Crack Pattern of Tested Beams

The beams broke under cyclic strain owing to internal rebar and polypropylene fibre fractures. As deflection and cycles increased, beam stiffness decreased. Flexural fractures arise with cyclic stress as deflection and cycles increase. As the beam cracks, the effective moment of area drops and deflection increases.

Compared to CBC and ECC0, 0.4% polypropylene fibre increased fracture width at ultimate stress by 28.57% and 20%, respectively. The number of fractures at ultimate load increased 120% with 0.4% polypropylene fibre compared to CBC and 69.23% with ECC0. The highest fracture spacing reduction at ultimate load was 44.35% with 0.4% polypropylene fibre compared to CBC and 34.91% with ECC0. Figs. 4.67–4.72 illustrate the beam specimen failure mechanism and fracture pattern.

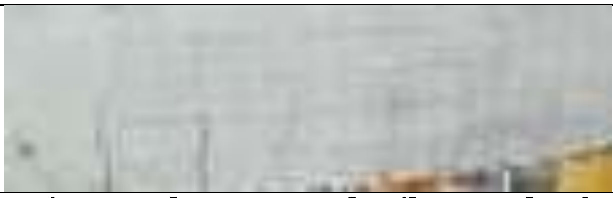

Fig 8 Crack Pattern and Failure Mode of CBC Beam

Fig 9 Crack Pattern and Failure Mode of ECCO Beam

Fig 10 Crack Pattern and Failure Mode of ECC1 Beam

Fig 11 Crack Pattern and Failure Mode of ECC2 Beam

Fig 12 Crack Pattern and Failure Mode of ECC3 Beam

Fig 13 Crack Pattern and Failure Mode of ECC4 Beam

Inclusion of PP fibres and ECA notably improved the mechanical, durability and microstructural properties of concrete. Introduction of PP fibres appreciably enhanced the load and deformation capacity as well as the ductility of SLWC beams subjected to static loading condition. Incorporation of PP fibres considerably augmented the cyclic performance of SLWC beams in terms of number of cycles sustained, stiffness, failure mode and total energy absorption.

5. CONCLUSIONS

Based on the results obtained through experiment, ANFIS modelling, regression analysis, reliability analysis and their discussion, the following conclusions are drawn:

- The incorporation of a 0.3% volume fraction of polypropylene fibres (EC3) increased the compressive strength of the expanded clay-based structural light-weight aggregate concrete by up to 19.83%.
- The use of polypropylene fibres improves the flexural strength of EC-based structural light-weight concrete significantly. With a 0.4% volume fraction of polypropylene fibres (EC4), a maximum improvement in flexural strength and 11.78% in modulus of elasticity were achieved.
- The use of polypropylene fibres not only enhances the overall performance of structural light-weight concrete, but it also aids in the prevention of brittle failure.
- The inclusion of 0.3% PPF (EC3) reduced water absorption and porosity by 0.39% and 0.5%, respectively. With 0.3% PPF (EC3), the largest decrease in strength loss and weight loss was 1.17% and 3.44%, respectively.
- The SEM pictures clearly show a more homogenous microstructure, which might be attributable to the uniform distribution of PP fibres as well as an enhanced link between the PP fibres and the matrix.
- In the presence of fibres, the intensity of peaks corresponding to CH crystals is significantly reduced in the XRD patterns.
- The addition of 0.4% volume fraction of polypropylene fibres (ECS4) to structural light-weight concrete beams with 20% expanded clay aggregates resulted in a 29.85% increase in load capacity, a 37.87% reduction in deflection, a 12.02% increase in deflection ductility, an 8.46% increase in energy ductility, and a 26.09% reduction in crack width.
- Under cyclic loading conditions, structural lightweight concrete beams have a 20% increase in the number of cycles and a 49.41% increase in total energy absorption capacity.
- Under static loading conditions, the beam specimens failed in flexure mode, while under cyclic loading conditions, they failed due to internal rebar fracture followed by concrete crushing.

SCOPE FOR FUTURE RESEARCH

A future study on the performance assessment of lightweight structural concrete beams comprised of expanded clay and polypropylene fibres has enormous potential to advance sustainable and resilient building materials. It would be critical to investigate the long-term durability, load-carrying capability, and structural behaviour of such composite materials under varied environmental conditions. Furthermore, experimenting with novel mix compositions that use varying amounts of expanded clay and polypropylene fibres might improve structural performance while being cost-effective. Further research might look at how various curing regimes and building practices affect the overall integrity of these beams. Advanced testing methods, like non-destructive testing and finite element analysis, might give useful insights into structural reactions and failure causes. This study might considerably contribute to the development of lightweight, environmentally friendly, and long-lasting building materials, promoting sustainable practices in the construction sector.

References

1. Özkılıç, Y. O., Karalar, M., Aksoylu, C., Beskopylny, A. N., Stel'makh, S. A., Shcherban, E. M., ... & Azevedo,A. R. (2023). Shear Performance of Reinforced Expansive Concrete Beams Utilizing Aluminium Waste. Journal ofMaterials Research and Technology. https://doi.org/10.1016/j.jmrt.2023.04.120
2. Wang, Y., Wang, Q., Li, Y., Wang, H., Gao, Y., Sun, Y.,... Zhan, M. (2023). Impact of incineration slag co-disposed with municipal solid waste on methane production and methanogens ecology in landfills. BioresourceTechnology, 377, 128978. doi: https://doi.org/10.1016/j.biortech.2023.128978

3. Chang, Q., Liu, L., Farooqi, M. U., Thomas, B., & Özkılıç, Y. O. (2023). Data-driven based estimation of waste-derived ceramic concrete from experimental results with its environmental assessment. Journal of Materials Re-search and Technology, 24, 6348-6368.
4. Fayed, S., Madenci, E., Özkiliç, Y. O., & Mansour, W. (2023). Improving bond performance of ribbed steelbars embedded in recycled aggregate concrete using steel mesh fabric confinement. Construction and BuildingMaterials, 369, 130452.
5. Yıldızel, S. A., Özkılıç, Y. O., Bahrami, A., Aksoylu, C., Başaran, B., Hakamy, A., & Arslan, M. H. (2023).Experimental Investigation and Analytical Prediction of Flexural Behaviour of Reinforced Concrete Beams withSteel Fibres Extracted from Waste Tyres. Case Studies in Construction Materials, e02227.
6. Çelik, A. L. I., & Özkılıç, Y. (2023). Geopolymer concrete with high strength, workability and setting timeusing recycled steel wires and basalt powder. Steel and Composite Structures, 46(5).
7. Huang, H., Yuan, Y., Zhang, W., & Zhu, L. (2021). Property Assessment of High-Performance Concrete Con-taining Three Types of Fibers. International Journal of Concrete Structures and Materials, 15(1), 39. doi:10.1186/s40069-021-00476-7
8. Zhang, W., Kang, S., Liu, X., Lin, B., & Huang, Y. (2023). Experimental study of a composite beam externallybonded with a carbon fiber-reinforced plastic plate. Journal of Building Engineering, 71, 106522. doi:https://doi.org/10.1016/j.jobe.2023.106522
9. Shi, T., Liu, Y., Zhao, X., Wang, J., Zhao, Z., Corr, D. J.,... Shah, S. P. (2022). Study on mechanical propertiesof the interfacial transition zone in carbon nanofiber-reinforced cement mortar based on the PeakForce tappingmode of atomic force microscope. Journal of Building Engineering, 61, 105248. doi:https://doi.org/10.1016/j.jobe.2022.105248
10. Tao Shi, Y. L. Z. H. Deformation Performance and Fracture Toughness of Carbon Nanofiber Modified Ce-ment-Based Materials. ACI Materials Journal, 119(5). doi: 10.14359/51735976
11. Thienel, K.-C.; Haller, T.; Beuntner, N. Lightweight Concrete—From Basics to Innovations. Materi-als 2020, 13, 1120. https://doi.org/10.3390/ma13051120
12. Acar, M. C., Çelik, A. İ., Kayabaşı, R., Şener, A., Özdöner, N., & Özkılıç, Y. O. (2023). Production of perlite-based-aerated geopolymer using hydrogen peroxide as eco-friendly material for energy-efficient buildings. Jour-nal of Materials Research and Technology, 24, 81-99. https://doi.org/10.1016/j.jmrt.2023.02.179
13. Agrawal, Y.; Gupta, T.; Sharma, R.; Panwar, N.L.; Siddique, S. A Comprehensive Review on the Performanceof Structural Lightweight Aggregate Concrete for Sustainable Construction. Constr. Mater. 2021, 1, 39-62.https://doi.org/10.3390/constrmater1010003
14. Bai, B., Bai, F., Nie, Q., & Jia, X. (2023). A high-strength red mud–fly ash geopolymer and the implications ofcuring temperature. Powder Technology, 416, 118242. doi: https://doi.org/10.1016/j.powtec.2023.118242
15. Zhou, S., Lu, C., Zhu, X., & Li, F. (2021). Preparation and Characterization of High-Strength GeopolymerBased on BH-1 Lunar Soil Simulant with Low Alkali Content. Engineering, 7(11), 1631-1645. doi:https://doi.org/10.1016/j.eng.2020.10.016
16. Sun, L., Wang, C., Zhang, C., Yang, Z., Li, C.,... Qiao, P. (2022). Experimental investigation on the bondperformance of sea sand coral concrete with FRP bar reinforcement for marine environments. Advances in Struc-tural Engineering, 26(3), 533-546. doi: 10.1177/13694332221131153
17. Özkılıç, Y. O., Başaran, B., Aksoylu, C., Karalar, M., & Martins, C. H. (2023). Mechanical behavior in termsof shear and bending performance of reinforced concrete beam using waste fire clay as replacement of aggre-gate. Case Studies in Construction Materials, 18, e02104.
18. Chang, Q., Liu, L., Farooqi, M. U., Thomas, B., & Özkılıç, Y. O. (2023). Data-driven based estimation of waste-derived ceramic concrete from experimental results with its environmental assessment. Journal of Materials Re-search and Technology, 24, 6348-6368.
19. Bamaga, S.O. A Review on the Utilization of Date Palm Fibers as Inclusion in Concrete and Mortar. Fi-bers 2022, 10, 35. https://doi.org/10.3390/fib10040035
20. Gu, M.; Ahmad, W.; Alaboud, T.M.; Zia, A.; Akmal, U.; Awad, Y.A.; Alabduljabbar, H. Scientometric Anal-ysis and Research Mapping Knowledge of Coconut Fibers in Concrete. Materials 2022, 15, 5639.https://doi.org/10.3390/ma15165639
21. Ahmad, J.; Majdi, A.; Deifalla, A.F.; Ben Kahla, N.; El-Shorbagy, M.A. Concrete Reinforced with Sisal Fibers(SSF): Overview of Mechanical and Physical Properties. Crystals 2022, 12, 952.