ISSN 2228-9860 eISSN 1906-9642 CODEN: ITJEA8

International Transaction Journal of Engineering, Management, & Applied Sciences & Technologies

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Effects of Polypropylene Fibres on the Properties of Reinforced Structural Lightweight Concrete Made With Expanded Clay Aggregates

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Paper ID: 13A5H

Volume 13 Issue 5

Received 14 January 2021
Received in revised form 8 April 2022
Accepted 15 April 2022
Available online 22 April 2022

Keywords:
Compressive strength; Expanded Clay Aggregate (ECA); Flexural strength; Lightweight concrete; Modulus of elasticity; Modulus of rupture; Polypropylene fibres.

Abstract

All efforts are being made to tailor the properties of concrete by replacing binder and filler with appropriate materials based on the environmental conditions. Many prospective players came into vogue for the purpose. Expanded clay showed promise for use in structural lightweight concrete. The addition of discontinuous discrete fibres proved to be beneficial in further improving the performance of structural lightweight concrete. A comprehensive laboratory investigation has been carried out to assess the influence of polypropylene fibres on the properties of expanded clay-based structural lightweight concrete. Expanded clay aggregates (ECA) have been used in varying percentages of 10%, 20%, 30%, 40% to replace coarse aggregates. Polypropylene fibres have been used in volume fractions of 0.1%, 0.2%, 0.3% and 0,4%. Based on trials, the optimum dosage of expanded clay aggregates for meeting the workability and strength requirements has been obtained. The laboratory results showed that the inclusion of polypropylene fibres improved the properties of structural lightweight concrete appreciably.

Disciplinary: Civil Engineering & Technology (Structural & Construction Materials).

Cite This Article:

Gaayathri, K.K., Suguna, K., Raghunath, P.N. (2022). Effects of Polypropylene Fibres on the Properties of Reinforced Structural Lightweight Concrete Made With Expanded Clay Aggregates. *International Transaction Journal of Engineering, Management, & Applied Sciences & Technologies, 13*(5), 13A5H, 1-11. http://TUENGR.COM/V13/13A5H.pdf DOI: 10.14456/ITJEMAST.2022.92

1 Introduction

Structural lightweight concrete is finding its place in many applications such as buildings, bridges, floors and partitions. The inherent characteristics of structural lightweight concrete that make it preferable include lower density, higher specific strength, good thermal insulation and better durability. The density of concrete is of primary concern in the context of the self-weight of structural members. In many structures, self-weight forms an appreciable proportion of the total load. Reduced density of structural lightweight concrete results in reduced self-weight of structural members which is quite important in seismic-resistant design. It is relatively understandable that the addition of micro-reinforcement enhances the overall performance in general. The improved mechanical properties of structural lightweight concrete as a result of the inclusion of micro reinforcement makes it fit for use in load-bearing structural members also.

The addition of steel fibre to high strength lightweight concrete is extremely effective in improving the strength and fracture toughness (Jianming Gao et al. 1997). The longitudinal tensile reinforcement ratio compatible with flexural ductility is somewhat lower for LWAC beams when compared to NWAC (Bernardo et al. 2016). The methods contained in the American code of practice (ACI 318-2005 and ACI 213-2003) for LWAC can predict the cracking and ultimate strength quite accurately (Lim et al., 2006). The optimal HPPFs content t of 1.1% and SFs content of 2.0% improved the flexural toughness of plain concrete (Li et al. 2017). The addition of 1.5% polypropylene fibre increased the compressive and split tensile strength. (Sohaib et al., 2018). The use of industrial waste steel wires can be used as micro–reinforcement for improving the mechanical properties of lightweight concrete. (Aghaee et al., 2014).

In this study, efforts have been made to study the behaviour of expanded clay-based structural lightweight concrete with the inclusion of polypropylene fibres in varying volume fractions.

In building systems, the dead load is of greater concern. Attempts need to be made to reduce the dead load as much as practicable. In this context, structural lightweight concrete gains importance (Sakthivel and Saravanan, 2022; Thongjub et al., 2022). The introduction of fibres into lightweight concrete enhances its flexural strength, compressive strength and deformation capacity appreciably. The sizes of member sections also get reduced leading to an economical solution. Further the serviceability of member sections also improves through reduced crack widths. Hence an attempt has been made to realise the impact of including polypropylene fibres on the properties of expanded clay-based structural lightweight concrete.

2 Experimental Programme

2.1 Materials

2.1.1 Cement

Ordinary Portland Cement of grade 53 conforming to IS 12269: 2013 was used in this investigation. The properties of cement used are given in Table 1.

Table 1: Properties of Cement

Property	Value
Specific gravity	3.15
Standard consistency	33%
Initial setting time	55 minutes
Final setting time	380 minutes

2.1.2 Coarse Aggregate

The coarse aggregate used was crushed granite of a maximum particle size of 20mm and conforming to IS 383:2016. Expanded Clay Aggregate (ECA)(Figure2) was used to partially replace coarse aggregate.

Table 2: Properties of Coarse Aggregate

Property	Crushed Granite Aggregate	Expanded Clay Aggregate
Specific gravity	2.68	0.57
Water absorption	0.7	15.5%
Shape	Angular	Rounded
Bulk density	1600 kg/m^3	600 kg/m^3

2.1.3 Fine Aggregate

A combination of natural river sand (R-sand) conforming to IS383: 2016 and manufactured sand (M-sand) was used as fine aggregate in this study. Trials were made to arrive at the combination of R-sand to M-sand. R-sand 55% and M-sand 45% combined were found to be beneficial. The specific gravity of the combine was found to be 2.66.

2.1.4 Polypropylene Fibre

Commercially available Recron 3S fibres (Figure3) were used in this study. The fibres are compatible with all admixtures used in concrete which conform to ASTM C1116.

Table 3: Properties of Polypropylene Fibres

Property	Value
Length	12mm
Shape	Triangular
Effective Diameter	40 micron
Specific Gravity	0.91
Tensile Strength	4 GPa
Elongation	90%
Elasticity Modulus	4000 MPa
Alkaline Stability	Very good

2.1.5 Super Plasticizer

An SNF based high range water reducing admixture Conplast SP430 (Figure1) was used to satisfy the workability demand of each mix. The product Conplast SP430 conforms to ASTM C494. The dosage for all the mixes was arrived at through trials.

Table 4: Properties of Super Plasticizer

Property	Value
Appearance	Liquid
Colour	Brown
Specific gravity	1.18
Chloride content	Nil

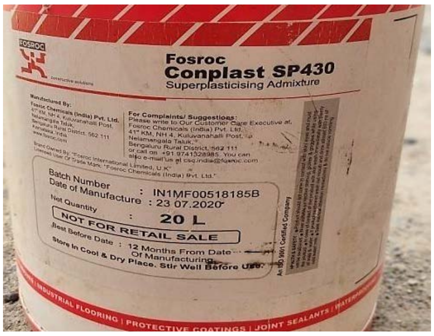

Figure 1: Super Plasticizer

Figure 2: Expanded Clay Aggregates

Figure 3: Polypropylene Fibres

2.2 Control Specimens

Cube Specimens (3 cubes for each mix) of size 150 X 150 X 150 mm were cast and tested for determining the compressive strength of concrete.

Cylinder Specimens (3 cylinders for each mix) of size 150 X 300 mm were cast and tested for determining the compressive strength of concrete.

Cylinder Specimens (3 cylinders for each mix) of size 150 X 300 mm were cast and tested for determining the elasticity modulus of concrete

Prism Specimens (3 prisms for each mix) of size 100 X 100 X 500 mm were cast and tested for determining the flexural strength of concrete.

2.2.1 Preparation of Control Specimens

The ingredients were first mixed in a dry state and then fibres were added in smaller quantities to avoid balling of fibres. The prepared wet (water plus SP) concrete was placed in equal layers in the moulds and thoroughly compacted. The specimens were removed after 24 hours from the moulds and then cured continuously for 28 days in a tank. After drying, the specimens were tested for compressive strength, elasticity modulus and flexural strength respectively. The details of control specimens are given in Table 5.

Table 5: Details of Control Specimens

Mix No.	Specimen	w/c Ratio	Water content (kg)	Cement (kg)	Coarse Aggregate (kg)	Expanded Clay Aggregate (kg)	River Sand (kg)	M-Sand (kg)	Fibre Volume %
1	EC0	0.5	175	350	995.8	52.17	377.85	309.15	0
2	EC1	0.5	175	350	995.8	52.17	377.85	309.15	0.1
3	EC2	0.5	175	350	995.8	52.17	377.85	309.15	0.2
4	EC3	0.5	175	350	995.8	52.17	377.85	309.15	0.3
5	EC4	0.5	175	350	995.8	52.17	377.85	309.15	0.4

2.3 Experimental Methods

2.3.1 Slump Test

The concrete mix has been designed as per IS 10262:2019. The workability test has been conducted for all the five mixes as per IS 1199:2008. The SP dosage used and the slump obtained for each mix are presented in Table 6. A standard mould of 300mm height, 200mm base diameter and 100mm top diameter was used. The fresh concrete was filled into the mould in equal layers and well compacted. The subsidence was measured after the removal of the cone.

Table 6: Slump Test Results

Sl No	Designation	SP % used	Slump(mm)
1	EC0	0.45	60
2	EC1	0.60	57
3	EC2	0.67	58
4	EC3	0.82	56
5	EC4	1.05	57

2.3.2 Compressive Strength Test

A total of 18cubes of size 150×150×150mm (control, with 20 % ECA, with 20% ECA plus 0.1% PPF, with 20% ECA plus 0.2% PPF, with 20% ECA plus 0.3% PPF and with 20% ECA plus 0.4% PPF) were tested as per IS516: 1999 in a standard Compression Testing Machine. Each value represents the average result of three specimens in the same group.

A total of 18 cylinders of size 150×300 mm (control, with 20 % ECA, with 20% ECA plus 0.1% PPF, with 20% ECA plus 0.2% PPF, with 20% ECA plus 0.3% PPF and with 20% ECA plus 0.4% PPF) were tested as per IS 516: 1999 in a standard Compression Testing Machine. Each value represents the average result of three specimens in the same group.

2.3.3 Elasticity Modulus Test

A total of 18 cylinders of size 150×300 mm (control, with 20 % ECA, with 20% ECA plus 0.1% PPF, with 20% ECA plus 0.2% PPF, with 20% ECA plus 0.3% PPF and with 20% ECA plus 0.4% PPF) were tested as per IS 516: 1999 in a standard Compression Testing Machine. The test set-up with appropriate instrumentation for this experiment is shown in Figure 4. Each value represents the average result of three specimens in the same group.

Figure 4: Elasticity Modulus Test on Cylinder

2.3.4 Flexural Strength Test

A total of 18 prisms of size 100× 100 X 500 mm (control, with 20 % ECA, with 20% ECA plus 0.1% PPF, with 20% ECA plus 0.2% PPF, with 20% ECA plus 0.3% PPF and with 20% ECA plus 0.4% PPF) were tested as per IS 516: 1999 in a standard loading frame. Figure 5 shows the test. Each value represents the average result of three specimens in the same group.

Figure 5: Flexure Test on Prism

3 Results and Discussion

3.1 Compressive Strength

The compressive strength of expanded clay-based structural lightweight concrete with varying fibre volume fractions of polypropylene fibre is presented in Table 7. The average compressive strength of the expanded clay-based structural lightweight concrete specimens was 23.55 MPa which confirms ASTM 213R-03. There was an increase in compressive strength by 3.77 % and 10.40 % with the inclusion of 0.1% and 0.2% volume fraction of polypropylene fibres respectively. The compressive strength of concrete with 0.3% volume fraction of polypropylene fibres increased appreciably reaching a peak value of 28.22 N/mm^2. The increase in cube strength may be due to the strong bond between the PP fibres and the matrix. However, the compressive strength of concrete with 0.4% volume fraction of polypropylene fibres got decreased. It is apparent that the decrease in compressive strength for this fibre content may be due to difficulty in dispersing the fibres in the concrete. The percentage gain in cube and cylinder compressive strength is shown in Figure 6 and Figure 7.

Table 7: Compressive Strength Test Results

Designation	Cube Compressive Strength (MPa)	% Gain in Cube Compressive Strength	Cylinder Compressive Strength(MPa)	% Gain in Cylinder Compressive Strength
EC0	23.55	-	18.84	-
EC1	24.44	3.77	19.58	3.93
EC2	26.00	10.40	20.94	11.15
EC3	28.22	19.83	22.64	20.17
EC4	25.42	7.94	20.37	8.12

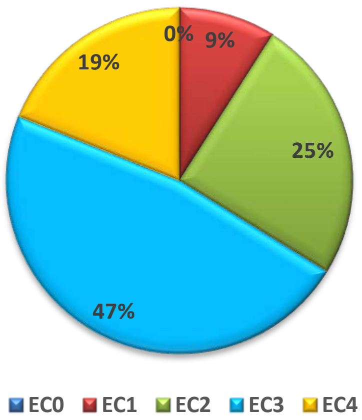

Figure 6: Cube Compressive Strength

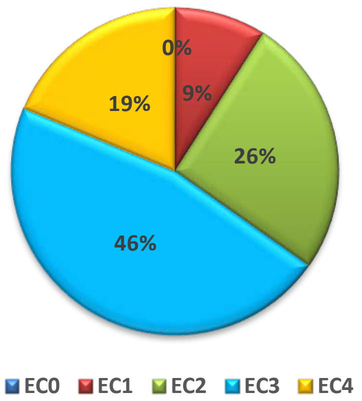

Figure 7: Cylinder Compressive Strength

3.1.1 Failure Pattern

The cube specimens were tested in a compression testing machine of 1000 kN capacity The failure pattern of polypropylene fibre based lightweight concrete cube specimens with expanded clay aggregate is shown in Figure 8. In the early stages, the cracks were concentrated on the surface only. With the increase in axial stress level, the cracks formed earlier propagated towards the interior of the cube specimens. Further, Concrete spalling also occurred at this stage. With the inclusion of polypropylene fibres, the failure pattern of cube specimens changed distinctly. The propagation of crack was found retarded. This is because the internally included polypropylene fibres created a confinement mechanism preventing the tendency of concrete to crack and spall. The volume fraction of polypropylene fibres have been found to influence the failure pattern of cube specimens significantly.

Figure 8: Failure Pattern of Cube specimens

3.2 Modulus of Elasticity

The elasticity modulus of expanded clay-based structural lightweight concrete with varying fibre volume fractions of polypropylene fibre is presented in Table 8. The results exhibit an increase of 0.86% in fibre reinforced lightweight concrete when compared to non-fibre reinforced concrete. With the further addition of polypropylene fibres, the elasticity modulus increased. The addition of polypropylene fibres by 0.3% increases the elasticity modulus by 10.17%. Similarly, a 0.4% volume fraction of polypropylene fibre increases the elasticity modulus by11.78%. The modulus of elasticity was found to increase with the increase in polypropylene fibre content due to the fibre bridging affecting the percentage gain in modulus of elasticity are shown in Figure 9.

Table 8: Elasticity Modulus Test Results

Designation	Elasticity Modulus (GPa)	% Gain in Elasticity Modulus
EC0	24.39	-
EC1	24.60	0.86
EC2	25.50	4.55
EC3	26.87	10.17
EC4	27.26	11.78

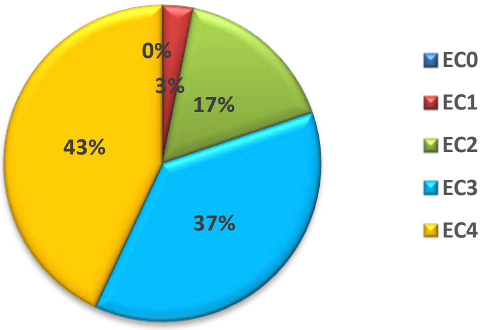

Figure 9: Modulus of Elasticity of Test Specimens

3.2.1 Failure Pattern

The cylinder specimens were tested in a compression testing machine of 1000 kN capacity. The failure pattern of polypropylene fibre based lightweight concrete cylinder specimens with expanded clay aggregate is shown in Figure 10. In the early stages, a major macro crack was observed over the height of the cylinder specimen. With an increase in axial compressive stress, more longitudinal cracks formed on the specimen surface. With the inclusion of polypropylene fibres, the failure pattern of cylinder specimens changed differently. The crack propagation was found retarded. There was also an increase in crack density. The polypropylene fibres caused a confinement mechanism preventing the tendency of concrete to crack and spall. The volume fraction of polypropylene fibres has been found to significantly influence the failure pattern of cylinder specimens.

EC0 EC1 EC2 EC3 EC4

Figure 10: Failure Pattern of Cylinder Specimens

3.3 Modulus of Rupture

The flexural strength test results of different mixes are presented in Table 9. Each test value is the mean value recorded from three test specimens. The flexural strength was found to increase from 4.7 N/mm^2 to 7.4 N/mm^2 with an increase in fibre volume fraction from 0% to 0.4%. The rate of increase of flexural strength was 10.64% to 54.45% based on the fibre volume fraction attempted. The increase in flexural strength with an increase in fibre volume fraction may be due to the fact that, after matrix cracking, the polypropylene fibres continue to share the load. The fracture process consisted of progressive fibre debonding during which crack propagation occurred slowly. The final failure occurred due to unstable crack propagation when the fibres pulled out. Figure11 illustrates the modulus of Rupture of expanded clay-based polypropylene fibre reinforced concrete.

Table 9: Modulus of Rupture Test Results

Designation	Modulus of Rupture (MPa)	% Gain in Modulus of Rupure
EC0	4.7	-
EC1	5.2	10.64
EC2	5.8	23.40
EC3	6.5	38.29
EC4	7.4	57.45

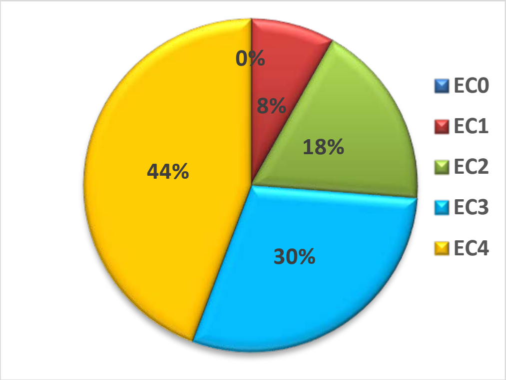

Figure 11: Modulus of Rupture of Test Specimens

3.3.1 Failure Pattern

The prism specimens were tested under four-point bending in a standard loading frame. The failure pattern of polypropylene fibre based lightweight concrete prism specimens with expanded clay aggregate is shown in Figure12. The pattern of failure was found to be the same in the specimens with and without polypropylene fibres except that the time of formation of crack as well as the width of crack was less. The increase in flexural strength with an increase in fibre volume fraction may be due to the restraint to crack growth caused by the PP fibre addition.

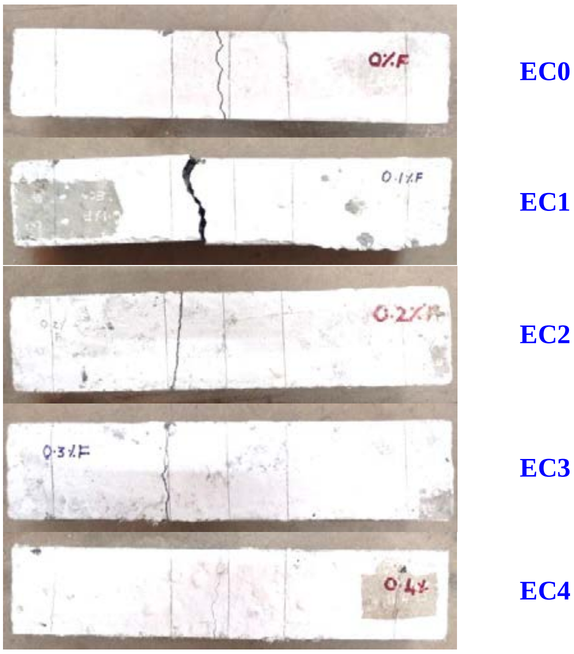

Figure 17: Failure Pattern of Prism Specimens

4 Conclusion

From this study, the expanded clay-based structural lightweight aggregate concrete showed a maximum of 19.83% increase in compressive strength with the inclusion of 0.3% volume fraction of polypropylene fibre., which may be due to the cracking resistance offered by the fibre reinforcement. The addition of polypropylene fibres is very effective in improving the flexural strength of structural lightweight concrete. A maximum increase of 57.45% has been obtained with 0.4% volume fraction of polypropylene fibres.

The modulus of elasticity increased at the rate of 0.86% to 11.78% as the fibre volume fraction increased from 0.1% to 0.4%. The incorporation of polypropylene fibres not only improves the overall performance of structural lightweight concrete but also helps in preventing the brittle failure of the material.

5 Availability of Data and Material

Data can be made available by contacting the corresponding author.

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