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A Study on Material Properties of Structural Light Weight Concrete with Micro-reinforcement

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Abstract

This paper presents the results of an experimental study on material properties such as mechanical properties and durability properties to examine the effectiveness of 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. Non-linear regression analysis was carried out to determine the relationship between the dependent variables such as compressive strength, Flexural strength and Modulus of elasticity for Structural Lightweight Concrete with polypropylene fibres and independent variables such as volume fraction of fibres and aspect ratio.

Disciplinary: Civil Engineering (Concrete Technology, Structural Engineering, Construction and Building Materials).

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1 Introduction

1.1 Information

The 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 fibres to high-strength lightweight concrete is extremely effective in improving the strength and fracture toughness [9]. The longitudinal tensile reinforcement ratios compatible with flexural ductility are somewhat lower for Light Weight aggregate Concrete beams when compared to Normal Weight Aggregate Concrete. The methods contained in the American code of practice (ACI 318-2005 and ACI 213-2003) for Light Weight aggregate Concrete can predict the cracking and ultimate strength quite accurately. The optimal HPPFs content of 1.1% and SFs content of 2.0% improved the flexural toughness of plain concrete. The addition of 1.5% polypropylene fibre increased the compressive and split tensile strength. The use of industrial waste steel wires can be used as micro-reinforcement for improving the mechanical properties of lightweight concrete (Gaayathri et al., 2022).

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.

2 Experimental Programme

2.1 Materials

Ordinary Portland Cement of grade 53 conforming to IS 12269: 2013 was used in this investigation. The coarse aggregate used was crushed granite of a maximum particle size of 20mm and conforming to IS 383:2016. Expanded Clay Aggregate was used to partially replace coarse aggregate. A combination of natural river sand conforming to IS 383: 2016 and manufactured sand was used as fine aggregate in this study. Trials were made to arrive at the combination of R-sand to M-sand. 55% R - sand and 45% M-sand combined were found to be beneficial. The specific gravity of the combine was found to be 2.66. Commercially available Recron 3S fibres were used in this study. The fibres are compatible with all admixtures used in concrete which conform to ASTM C1116. A SNF based high range water reducing admixture Conplast SP430 was used to satisfy the workability demand of each mix

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.

Table 1: Details of Control Specimens

Designation	Water content (kg)	Cement (kg)	Coarse Aggregate (kg)	Expanded Clay Aggregate (kg)	River Sand (kg)	M- Sand (kg)	Fibre Volume %
EC0	175	350	995.8	52.17	377.85	309.15	0.0
EC1	175	350	995.8	52.17	377.85	309.15	0.1
EC2	175	350	995.8	52.17	377.85	309.15	0.2
EC3	175	350	995.8	52.17	377.85	309.15	0.3
EC4	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 shown in Figure 1. 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.

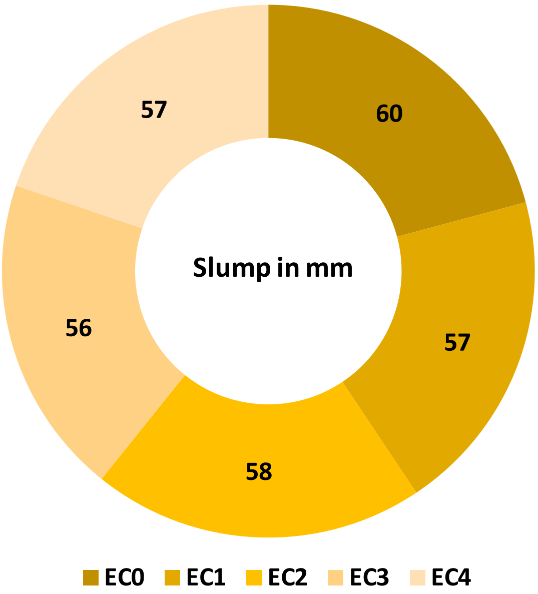


Figure 1: Slump Test Results

2.3.2 Mechanical Properties

A total of 18cubes, 18 cylinders, and 18 prisms (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 according to standard documents of Indian standards. The cubes were tested as per IS516: 1999 in a standard Compression Testing Machine for determining compressive strength. The cylinders were tested as per IS 516: 1999 in a standard Compression Testing Machine and tested as per IS 516: 1999 in a standard Compression Testing Machine for determining the cylinder compressive strength and modulus of elasticity. The prisms were tested as per IS 516: 1999 in a standard loading frame for determining the modulus of rupture. Each value represents the average result of three specimens in the same group.

2.3.3 Durability Properties

A) Water Absorption and Porosity

Cubes Specimens 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 for water absorption as per ASTM C642-97. Each value represents the average result of three specimens in the same group. The initial specimen weight was taken. Then the specimen was immersed in water for 48hrs. The specimen was surface dried with a towel and saturated mass after immersion was measured. The specimen was boiled for 5 hours, allowed to cool and the saturated mass after boiling was measured.

Figure 2: Boiling of Cubes

B) Sorptivity

Disc specimens of 100mm diameter and 50mm thickness were tested for the capillary rise of water as per ASTM C1585-04. Each value represents the average result of three specimens in the same group. An adhesive tape was used to maintain the path of the capillary rise of water. The mass of the disc was taken for 6 hours at time intervals of 30 minutes. The specimen was surface dried each time before weighing.

Figure 3: Disc sealed with adhesive tape

Figure 4: Sorptivity Test Setup

C) Acid Resistance

Cubes specimens of size 150×150×150mm were tested for Acid Resistance as per ASTM C1012. Each value represents the average result of three specimens in the same group. The initial weight of the specimens was taken. The acid medium was prepared (5% concentration of H_2SO_4). The specimens were kept immersed for 28-days in the prepared acid medium. The weight and strength loss after the immersion period was found.

(a) H2SO4 Acid (b) Cubes on Acid Attack (c) Cubes after Acid Attack (d) Testing

Figure 5: Acid Resistance Tests.

3 Result and Discussion

3.1 Mechanical Properties

The compressive strength of expanded clay-based structural lightweight concrete with varying fibre volume fractions of polypropylene fibre is presented. The average compressive strength of the expanded clay-based structural lightweight concrete specimens was 23.55 MPa which conforms to ASTM 213R-03. The compressive strength of concrete with a 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. The elasticity modulus of expanded clay-based structural lightweight concrete with varying fibre volume fractions of polypropylene fibre is presented. The results indicate an increase of 0.86% for fibre-reinforced structural lightweight concrete when compared to non-fibre-reinforced structural lightweight concrete. The flexural strength test results for different mixes are presented. 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 fracture process consisted of progressive fibre debonding during which crack propagation occurred slowly. The compressive strength, modulus of elasticity and modulus of rupture are presented in Table 2 and shown in Figure 6.

Table 2: Mechanical Properties of all the Test Specimens

Designation	Cube Compressive Strength	Cylinder Compressive Strength	Modulus of Elasticity	Modulus of Rupture
CC	33.33	26.71	28.21	6.5
EC0	23.55	18.84	24.39	4.7
EC1	24.44	19.58	24.60	5.2
EC2	26.00	20.94	25.50	5.8
EC3	28.22	22.64	26.87	6.5
EC4	25.42	20.37	27.26	7.4

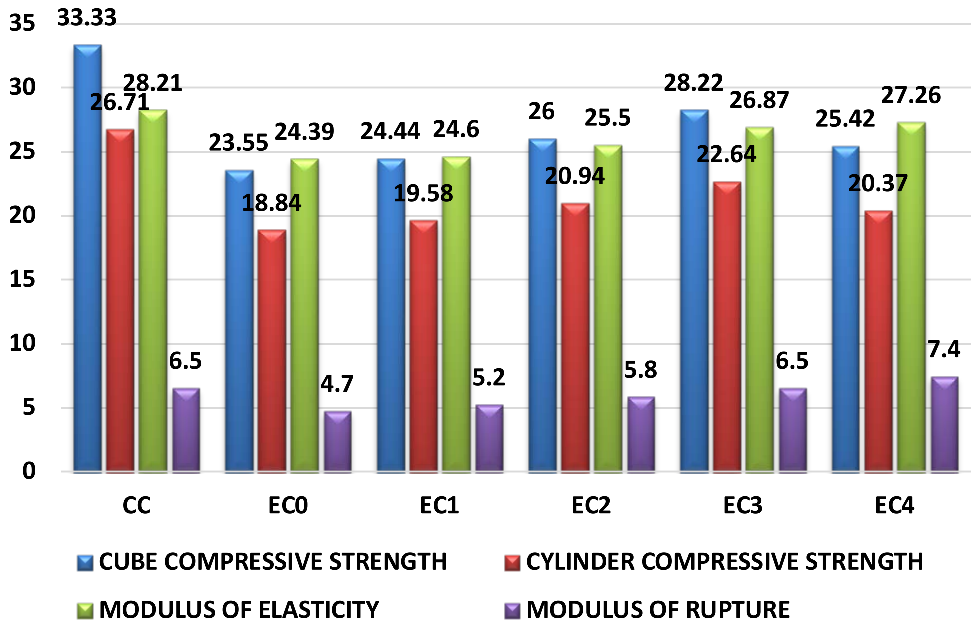


Figure 6: Mechanical Properties of all Test Specimens.

3.2 Durability Properties

3.2.1 Water Absorption

The water absorption percentage of Structural Lightweight Concrete with the inclusion of Polypropylene Fibres is furnished in Table 3. Structural lightweight concrete with 0% fibre exhibited increased absorption when compared to control concrete. The addition of 0.1%,0.2% and 0.3 % fibre volume fraction resulted in a decreasing trend in the absorption of water. This tendency may be due to uniform fibre dispersion. A slight increase in absorption was seen for the concrete with a 0.4% volume fraction of fibres. This may probably be due to the agglomeration of fibres. Figure 7 shows the effect of fibres on water absorption.

Table 3: Percentage of Water Absorption.

Designation	Percentage of Water Absorption
CC	0.46
EC0	0.65
EC1	0.61
EC2	0.47
EC3	0.39
EC4	0.44

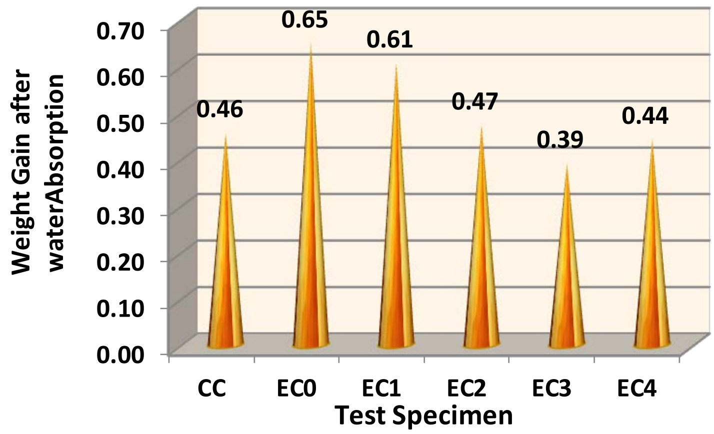


Figure.7: Effect of fibre on water Absorption

3.2.2 Porosity

The porosity of Structural Lightweight Concrete with the inclusion of Polypropylene Fibres is presented in Table 4. The expanded clay aggregate itself is a porous material which has a higher absorption percentage when compared with the normal weight aggregate. The cube specimens with lightweight aggregate exhibited an increased porosity when compared to normal weight aggregates. The voids got reduced with the inclusion of PP fibres of volume fraction 0.1%.0.2%,0.3% respectively. The stitching action of fibres facilitated the reduction in pores. An increase in porosity was observed with a 0.4% volume fraction of PP fibres owing to the collation of fibres. Figure 8 shows the effect of PP fibres on voids.

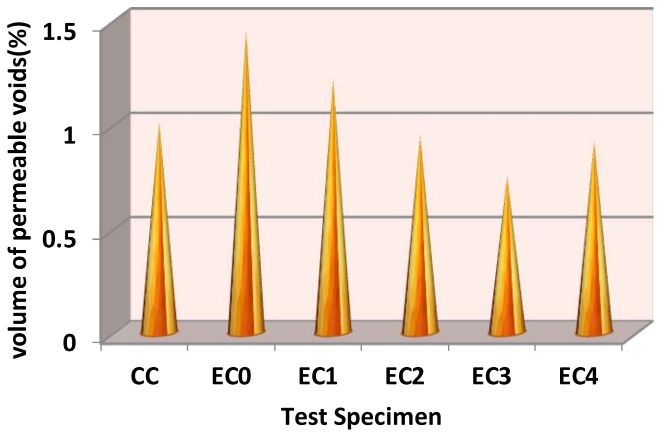


Figure 8: Effect of PP Fibres on voids (%).

Table 4: Porosity Parameters

Designation	Saturated Water Absorption	The volume of Permeable voids (%)
CC	0.65	1.01
EC0	0.83	1.45
EC1	0.61	1.21
EC2	0.47	0.95
EC3	0.37	0.75
EC4	0.45	0.92

3.2.3 Sorptivity

Sorptivity is the capacity to absorb water through the capillary rise in the hardened concrete. The sorptivity depends on the porosity of concrete. The sorptivity is reduced with the inclusion of PP fibres of a volume fraction of 0.1%.0.2%,0.3% respectively. The bridging action of fibres would have facilitated the reduction in sorptivity. An increase in porosity was observed with a 0.4% volume fraction of PP fibres owing to the bundling of fibres. Figure 9 shows the absorption with respect to time.

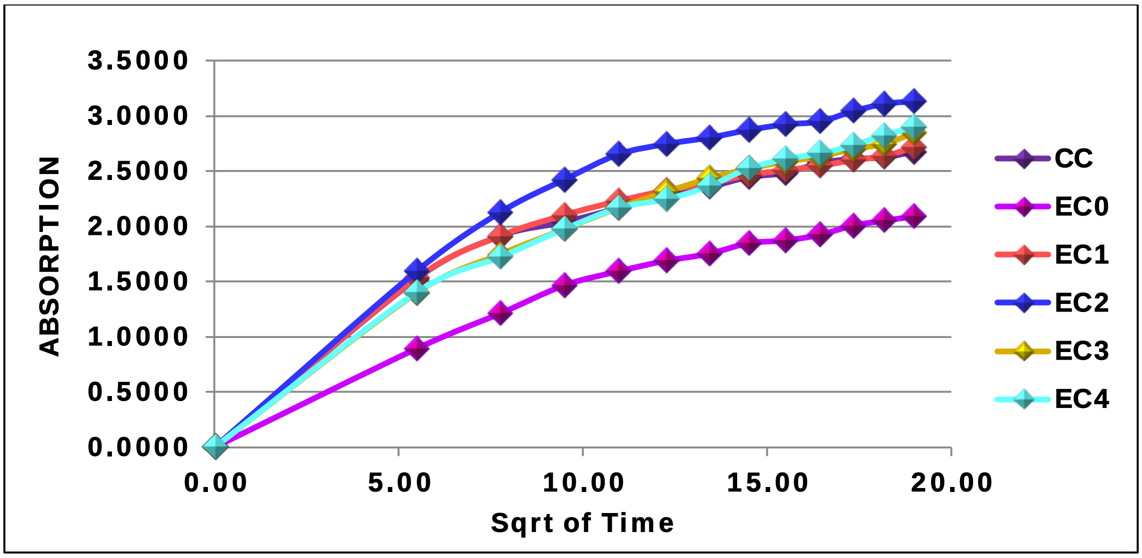


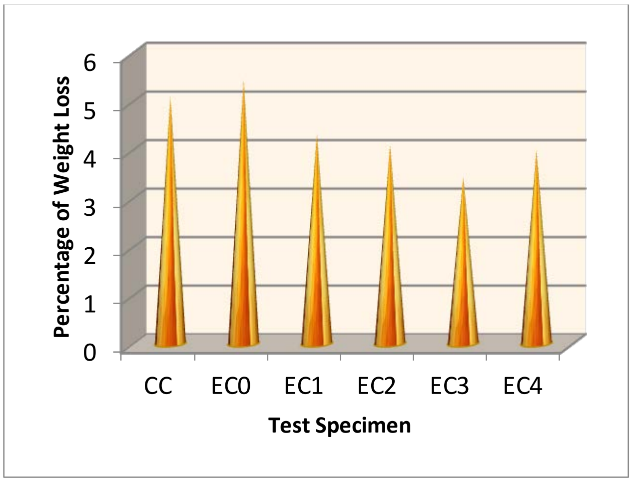
Figure 9: Absorption Vs Sqrt of Time

3.2.4 Acid Resistance

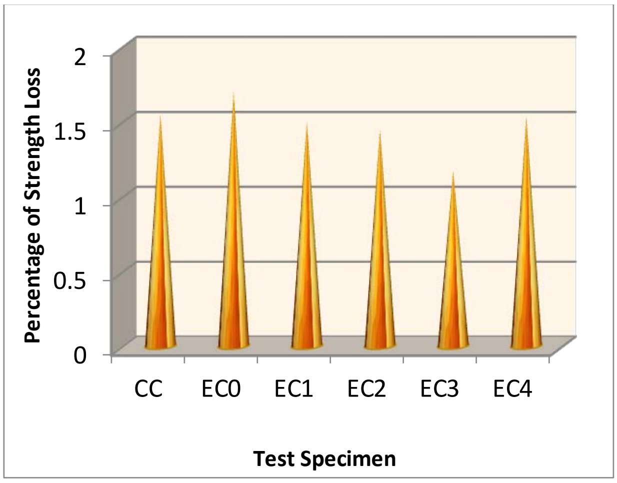
The percentage loss in weight and strength of Structural Lightweight Concrete with the inclusion of Polypropylene Fibres is furnished in Table 5. Structural lightweight concrete with 0% fibre showed a higher loss in weight and strength when compared to control concrete. The addition of 0.1%, 0.2% and 0.3 % fibre volume fraction resulted in a decreasing trend of loss in weight and strength. This may be because of a reduction in voids as a result of uniform fibre dispersion. A slight increase in loss in weight and strength was noticed for the concrete with a 0.4% volume fraction of fibres. This may probably be due to the balling of fibres. The effect of PP fibres on the loss of weight and strength is shown in Figure 10.

Table 5: Percentage Loss on Weight and Strength

Designation	Percentage of Weight Loss	Percentage of Strength
CC	5.10	1.55
EC0	5.44	1.0
EC1	4.32	1.5
EC2	4.10	1.45
EC3	3.44	1.17
EC4	3.99	1.53



(a)



(b)

Figure 10: Effect of fibres on Acid Resistance

4 Regression Analysis

Regression analysis is a set of statistical processes for estimating the relationships among variables. The regression might be used to identify the effect of independent variables over the dependent variable. Thus the regression analysis helps us to understand how much the dependent variable changes with a change in one or more independent variables. The non-linear regression analysis has been conducted using SPSS. Non-linear regression relates two variables in a curved form.

The model for multiple Non-linear regression takes the form

$$yf=(a*y)+(b*vf)+(c*vf*vf)+(d*vf*l/d) \qquad (1).$$

Table 6: Regression Equation for structural lightweight concrete with PP Fibre

Sl.No	Prediction Paramaters	Regression Equation
1	Compressive Strength	(0.979*fck)+(23191.438*vf)-(47.999*vf*vf)-(66.185*vf*l/d)
2	Flexural Strength	(1.002*fck)-(54911.732*vf)+(6.429*vf*vf)-(302.043*vf*l/d)
3	Modulus of Elasticity	(0.994*fck)+(105720.804*vf)+(5.929*vf*vf)+(156.902*vf*l/d)

Non-linear regression analysis was carried out to determine the relationship between the dependent variables such as compressive strength, Flexural strength and Modulus of elasticity for Structural Lightweight Concrete with polypropylene fibres and independent variables such as volume fraction of fibres and aspect ratio. The proposed regression equations are presented in Table 6.

Table 7: Statistical Indicators

Prediction Paramaters	RMSE	R^2	MAPE
Compressive Strength	0.8599	0.9988	2.9859
Flexural Strength	0.0414	0.9999	0.5593
Modulus of Elasticity	0.2470	0.9999	0.8939

The statistical error coefficients show the correlation between the experimental and predicted results. The RMSE, R^2, MAPE values are presented in Table 7. The regression equations proposed closely predict the performance parameters of Structural Lightweight concrete with Polypropylene Fibres. The experimental and predicted values are shown in Figure 8.

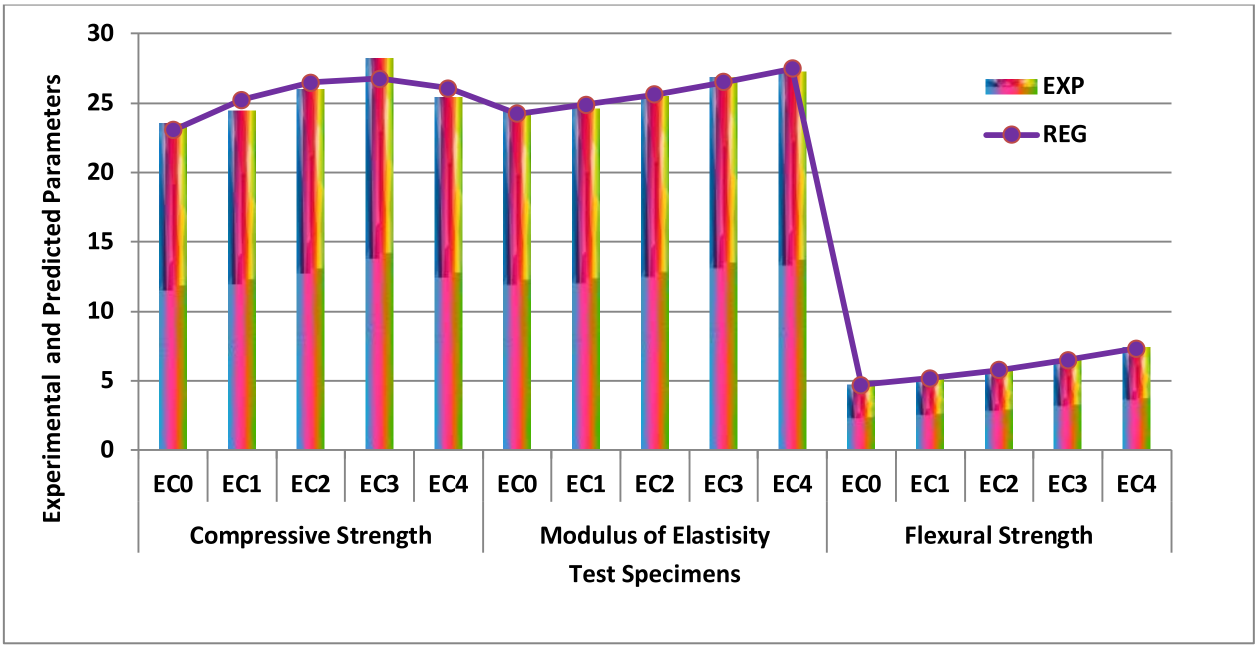


Figure 8: Experimental vs Predicted Parameters

5 Conclusion

The expanded clay-based structural lightweight aggregate concrete showed a maximum of 19.83% increase in compressive strength with the inclusion of a 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 a 0.4% volume fraction of polypropylene fibres.

The modulus of elasticity of Expanded Clay-based Structural Lightweight Concrete 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.

A noticeable improvement has been observed in respect of durability parameters such as water absorption, porosity, sorptivity and acid resistance owing to the bridging action caused by the PP fibre inclusion.

A good agreement has been observed between the results predicted through the proposed non-linear regression equations and the test results.

6 Availability of Data and Material

Data can be made available by contacting the corresponding author.

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