FLEXURAL STRENGTH ANALYSIS OF FIBRE REINFORCED ENGINEERED CEMENTITIOUS COMPOSITES USING RICE HUSK ASH

[1]**K.B. Shoba**

Associate Professor, Department of Civil Engineering
St. Peter's Institute of Higher Education & Research, Chennai, Tamilnadu, India
Email:haridrab002@gmail.com
[2]**P.Partheeban.**

Professor and Dean, Department of Civil Engineering,
Chennai Institute of Technology, Chennai, Tamilnadu, India.
Email: dean.pd@citchennai.net

[3]**V.B.M.Sayana**
Professor and Head, Department of Civil Engineering
St. Peter's Institute of Higher Education & Research, Chennai, Tamilnadu, India
Email:vbms19@hotmail.com

ABSTRACT

This article aims to evaluate the flexural strength of Engineered Cementitious Composites (ECC) incorporatingRice Husk Ash (at 5% to 25%) as a replacement for cement and polypropylene fibre (at 0.5% to 2.0%) added to serve as micro reinforcements in the cementitious composites. The ECC mixes were grouped based on the percentage replacement of rice husk ash for cement and percentage addition of fibers. Standard prism specimens conforming to BIS be cast to test the flexural capacity of these ECC mixes with that of control specimen. The test specimens were produced with a constant w/c ratio of 0.30 and exposed to water curing for 28 days strength. All the prism specimens were subjected to flexure test to determine its flexural capacity.The specimen achieving the maximum flexural strength was considered to be the optimum mix among all the ECC mixes. From the test results, it was found that the ECC mix with 10% rice husk ash replacement and 0.5% fibre addition produced the maximum flexural strength. This optimized mix specimen was considered for finite element modeling and analysis in the ANSYS software. The FEM analysis showed a reasonable agreement with the experimental test results in terms of stresses and deformations.

Keywords: ECC,Finite Element Analysis, Rice husk ash, Polypropylene Fibre, Flexural Strength

1. INTRODUCTION

Supplementary cementitious materials (SCMs) are used to mitigate the alkaline reactivity and to improve overall hardness through hydraulic or pozzolanic activity, including improved durability, reduced permeability, improved permeability, and reduced enduring capacity. In addition to or partially replacing Portland cement or mixed cement, SCMs are additionally applied to concrete and are usually considered to form part of the total cementing systems. The most common SCMs used in the construction industry include, Flyash, Ground Granulated Blast Furnace Slag, Silicafume or Microsilica, Rice Husk Ash, Metakaolin clay and more.Fiber-reinforced cement composites have steadily increased over the last 40 years. The fibers are added to control the cracking of fiber-reinforced cemented composites and alter the material's behavior after the cracked matrix, bridging the splits and improving ductility post-cracking. The structure depends upon the characteristics of fiber-reinforced cemented materials. Made of high-performance fiber-reinforced cement composites (ECCs), the producer ensures high flexibility and fiber content optimization.

The development of green-engineered cement composites in which the high cement levels are the result of the rheological control of fiber dispersion has been advanced to encourage the conservation of natural resources and to reduce the environmental impact of building materials in the construction industry. Restrictions on the toughness of the matrix fracture are essential, as multiple cracks occur before the bridging stress of the fiber is maximized. Among them, high tensile ductility is several hundred times that of concrete while maintaining the compressive strength of that high-strength concrete.

ECC's metal-like characteristics can be achieved without depending on the high fiber content. A moderate addition of 2% or lower volume fibers makes the ECC easy to adapt to the construction project in the field or to prevent the production of plant structural elements. ECC has shown flexibility in processing paths, including casting and spraying on site and precasting extrusion. ECC's large tensile ductility makes it compatible with deformations and provides the structural components with a synergistic capacity of load sharing with steel reinforcement. As a result, steel strengthening is better used in enhancing structural performance in strengthened ECC members. At the same time, the lower crack width of the ECC protects the reinforcing steel against typical corrosive processes, which increases the structural durability.Fibres play a pivotal role in adhering external forces. Applying fibre reinforced materials as external load carrying agents received good attention from structural validation and in concrete industry where the dependency factor for engineered cementitious composites are the physical parameters of cementitious materials and fibres.

The material was successfully used for retrofitting dams, skyscrapers, bridge decks, and other structural components and systems. Several full-scale ECC applications have been implemented in different countries in recent years. ECC in precast strengthened ECC beams in the core of two higher-surface buildings in Japan is one of the most important. This application exploits the reinforced ECC's high energy absorption capability to help these large buildings with seismic resistance.

The percentage of mineral additive rice husk ash when higher than thecalciumhydroxidelevelthen it leads to increase in compressive strength of composites, **Feng Qing-geet et. al., (2004).**Polyvinylalcohol fiberenhanced engineered cementitious composites(PVA-ECC) is highly efficient inproviding long-term benefits to repaired structures due to its energyabsorption, strain-hardeningperformance, strong crack width regulations and delamination resistance, **Kim et. al., (2004).**High earlystrength blend ECCmaterialshavebeendevelopedbasedondifferentbindingsystems(using rapid hardeningcement, standard Portland cement and Portland cement type III) undermicromechanicalmodels'guidance, **Shuxin Wang et. al., (2006).**The carbon content of fibers in the green sand ECCinstantly rises substantially compared to thatof ECC M45 which is an implication of carbon particle concentration at the PVA fiber and matrixinteraction, **Michael Lepech et. al.,(2007).** ECC'sintrinsicallytightcrackwidthhasprovedinfluential for long-life oftheinfrastructure due to extraordinary impairment restraints and high toughness atstandard service and severe loading conditions, **MustafaSahmaranet.al.,(2008).**Modification in the blending sequence or mixing seriesby the process of trial outcomes of uniaxialtensileassessmentandfiberdiffusioninvestigationenhances the fiber propagationand distribution thereby raising the ECC's tensile strain potential and ultimate tensilestrength, **Zhou et. al., (2012).**Super-hydrophobicengineeredconcretecomposite (SECC), is a current advanced concrete composition incorporatingpolyvinylalcoholicandhydrophobicchemicals.Thematerial'shighermechanicalperformance, dependability, reliabilityandlongevitystands as an excellent alternativetostandard concrete, **Sobolevet.al.,(2013).**The bending strength increases marginallywith 10% to 25% replacementof cement by rice husk ashand appearsto be effective in structuralconcretereplacement, **GodwinAkekeet.al.,(2013).**Manufacturingof PolyvinylAlcohol(PVA)engineered cement composites usingamicromechanicalmodelwithstresspotentialsof3%to5%and compared with a standard concrete of 0.1% showsthatthecompositeshaveahighlevelofstresshardship, **Srinivasa et. al., (2014).**Integration ofsilica fume into fiber-reinforcedcementitiouscompositesimprovesmatrixbondsbypore-refinedproducts and betterhydrationproduct distribution and also achieves 0.2% higherstrengthatalowervolume comparedtocement mortar, **Ramya et. al., (2014).**Application offiber, iflessthan2% thenextensivestrainhardeningbehaviorofthecompositeis noticed, **Chethanet.al.,(2015).** Higher flexural strengthcharacteristics in variousbendable concreteis possible by the addition of extra cementitious materials such asflyash and reconfigured fibers, **Madhaviet. al., (2016).**

Combination of rice husk ash and reinforcing polypropylene fibres in composites will enhance the mechanical properties of ECC such as hardness, impact, potential and tensile strength holding better reliability. To identify the suitability of the stated materials influencing theflexural strength under the impact of different forces in various conditions is utmost importantforexamination. The main objective of this experimental study is to develop a new engineered cementitious composite (ECC) material using rice husk ash, manufactured sand and polyproline fibre and determine the optimum percentage among the various ECC mixtures that achieves the significant performance in the flexural property.

2. EXPERIMENTAL INVESTIGATION

2.1 Materials and Properties

Controlled pyrolysis (burning) of the rice husk is performed to obtain Rice Husk Ash (RHA).RHA is a renewable and locally available agricultural residue in a significant quantity whose annual rice production in developing countries reached not more than 500 million tonnes with about 100 million tonnes available for use annually in our country. The content of rice husk is probably 20% high in ash whereas silica is 90%. It also looks porous with an enormous surface area and is very lightweight. As it is highly absorbent, a large volume of RHA is regarded as waste and dumped of at the waste disposal sites. Rice husk ash is used as a pozzolanic material in the construction industry to extract silica content. The amorphous nature of silica depends on temperature and its crystalline form when it is burned. It is highly reactive only if it has an excellent grain distribution particle size. The excess heating required for standard Portland cement in production leads to partially lower energy consumption, reducing carbon dioxide emissions as rice husk ash is replaced with cement.

As per ASTM 618C Standards, rice husk ash consistsof 90% silicon dioxide which can be used in the pozzolanic format. Once RHA is used for grinding, it dramatically diminishes the impact of water absorption. However, ash cement with a weight of upto 50 percent had compressive strengths significantly higher than the Portland control cementeven at an early age of seven days. RHAcontaining blocks of cement give outstanding resistance to dilute organic and mineral acids. The demand for water to obtain normal consistency tends to rise. However, incorporating water reduces compound admixtures by increasing the ash content of the mixed cement. RHA improves extensibility and workability and also lowers the cost. It reduces susceptibility to acid attack, improves resistance to chloride penetration and reduces large pores andporosity, resulting in very low permeability. It minimizes the micro-cracking, decreases the system's permeability, improves overall resistance to Co2 attack and improves capillary suction.

Table 1 provides the physical properties test results of rice husk ash.

Table 1.Physical Properties of Rice Husk Ash

S. No.	Physical Properties	Values
1	Specific gravity	2.94
2	Fineness	29.3%
3	Normal consistency	47.7 to 51.6%
4	Initial setting time	125 to 190 mints
5	Final setting time	250 to 305 mints
6	Soundness	0.012 to 0.033%
7	Compressive strength	47.7 to 51.6 MPa

Table 2 provides the chemical composition test results of rice husk ash conforming to IS 12803: 1989.

Table 2.Chemical Composition of Rice Husk Ash

S. No.	Oxide	Values%
1	Silicon dioxide (SiO2)	91
2	Aluminium oxide (Al2O3)	0.11
3	Ferric oxide (Fe2O3)	0.10
4	Sodium Oxide (Na2O)	0.13
5	Potassium Oxide (K2O)	3.10
6	Calcium Oxide (CaO)	0.46
7	Magnesium Oxide (MgO)	0.88
8	Sulphur Trioxide (SO3)	0.15
9	Phosphorous oxide (P2O5)	0.60
10	Loss of Ignition (LOI)	4.63

Polypropylene is one of the cheapest & abundantly available polymers.In situations where thevulnerable cementitious matrix which would deteriorate first under aggressive chemical attack, polypropylene fibers come into rescue as they are resistant to most chemicals. As its melting point is high about 165^{o}C, a working temperature of 100^{o}C may be sustained for short periods without detriment to fiber properties. Polypropylene fibers being hydrophobic in nature can be easily mixed as they do not need lengthy contact during mixing and only need to be evenly dispersed in the mix. Polypropylene short fibers in small volume fractions between 0.5% to 2%are commercially used in concrete.Composite materials containing polypropylene fibres has ductile property combined with resinous matrix. Table3, provides the properties of polypropylene fibre.

Table 3.Properties of Polypropylene Fibre

S. No	Description	Results	Unit
1	Length of fibre	3.50	mm
2	Density	0.91	g/cc
3	Colour	White	--
4	Diameter of fibre	38	µm
5	Tensile strength	>500	MPa
6	Elongation rate	>15	%
7	Melting & Burning point	180°&>360°	Celsius

2.2 Flexure Test Methodology

The tensile strength of concrete is indirectly assessed using the flexural test. It determines if an unreinforced concrete beam or slab can survive bending failure. The modulus of rupture is another term for flexural strength. Apart from the aforementioned factors, flexural strength is affected by formwork, ambient and mixing temperatures, humidity and curing. Flexural strength analysis is performed to determine deflections and stresses induced by cracks in the concrete under examination. Cracks have a direct impact on the concrete, exposing steel reinforcements to corrosion over time and are also affected by the water/cement ratio.With respect to the flexural property of engineered cementitious composites, flexural strength denotes the ability to resist the forces adhered in static as well as in dynamic environments trying to pull out the component thereby being fractured at elastic phase.

Prism specimens were tested for flexure inaccordancewithIS516:1959(Reaffirmed2004)–

Methodsof tests for strength of concrete under section 7.3.The standard size of the test specimens as per the Code requirementswas 7.5 cm × 5 cm × 35 cm.In overall, a total of 78 sampleswere testedand among that 3 samples from each identity were considered for evaluating the flexural strength of M45 grade of fibre reinforced ECC specimens. Figure 1, shows the casting and testing of fibre reinforced ECC prism specimens made with Rice Husk Ash (RHA) as cementitious material.

a. Casting **b. Testing**

Figure 1. Fibre Reinforced ECC-RHAPrism Specimens

In view towards the flexural property of engineered cementitious composites, the coupon specimen undergoes compressive stress at its surface in concave manner and tensile stress in convex manner. Flexural strength shall be calculated using the following formula:

$$\text{Stress} = 3PA/2bd^2$$

Where,

Stress = Flexural strength (N/mm^2)

P = Maximum load (N)

A = Distance between the line of fracture and nearer support (mm)

b and d = width and failure point depth of the specimen (mm)

2.3 Test Results and Discussion

2.3.1Effect of Flexural Strength on ECC-RHA Specimens

Flexural Strength, also known as modulus of rupture, bend strength or transverse rupture strength, is a material property defined as the stress in a material just before it yields in a flexure test, Michael Ashby (2011). It determines whether if an unreinforced concrete beam or slab can survive bending failure. Apart from the factors above, flexural Strength is affected by formwork, ambient and mixing temperatures, humidity and curing. Flexural strength analysis is performed to determine deflections and stresses induced by cracks in the concrete under examination. Trials directly impact the concrete, exposing steel reinforcements to corrosion over time and are also affected by the water/cement ratio.

The flexural strength was tested for the w/c ratio of 0.30 with varying rice husk ash replacement percentages of 5%, 10%, 15%, 20% and 25% and addition of polypropylene fiber percentages in 0.5 %, 1.0%, 1.5% and 2.0%. Figure2, shows the flexural strength of ECC control specimen and Figure3, showsthe flexural strength of ECC-RHA specimens at various percentages of rice husk ashand polypropylene fibersrespectively.

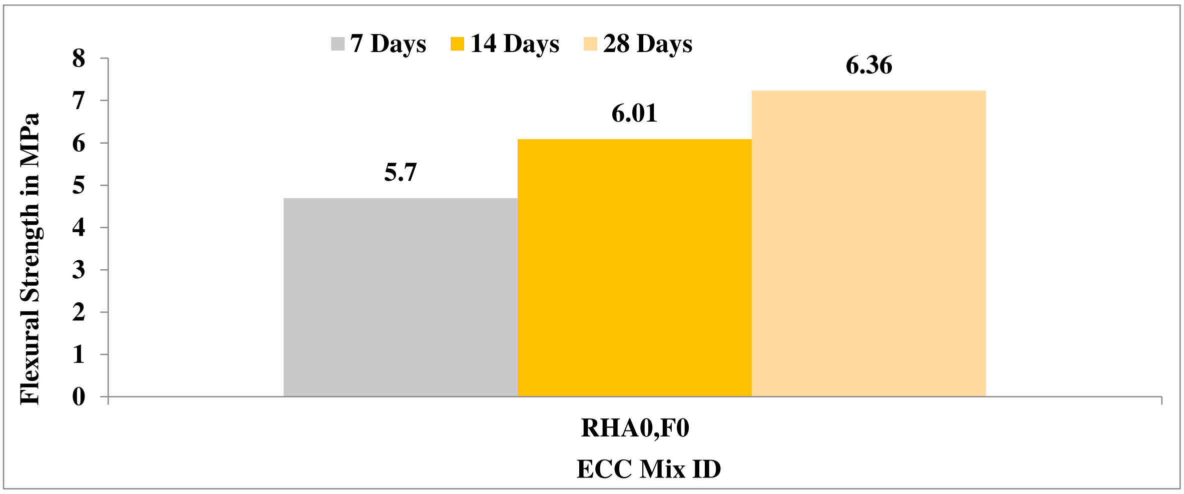


Figure 2. Flexural Strength of ECC Control Specimen

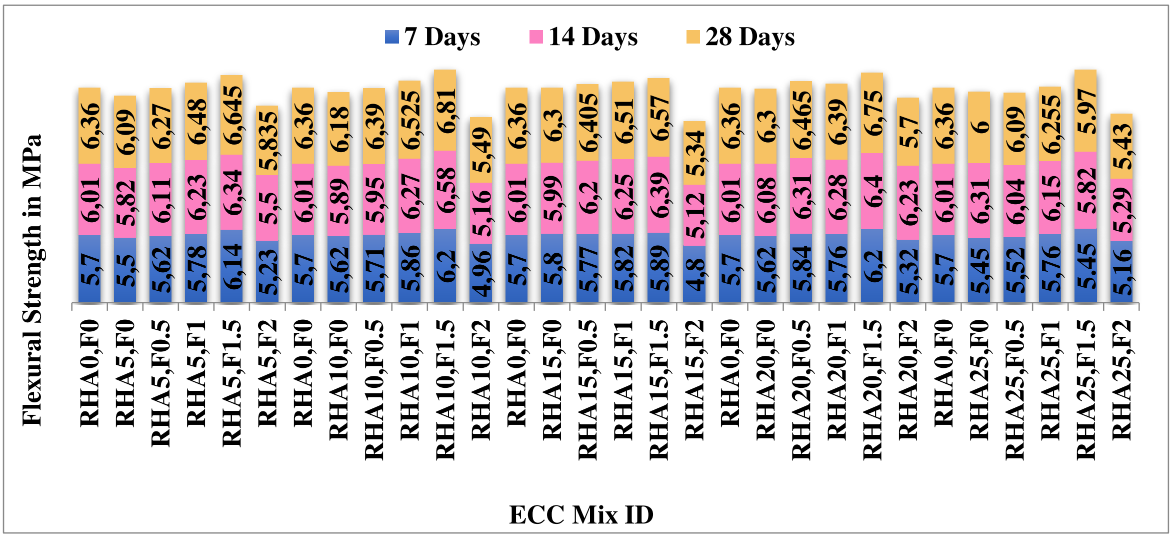
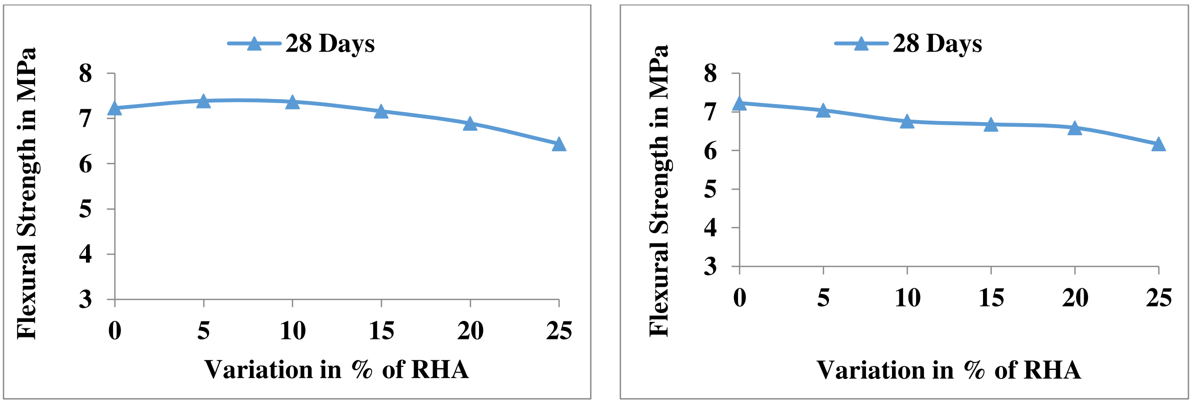


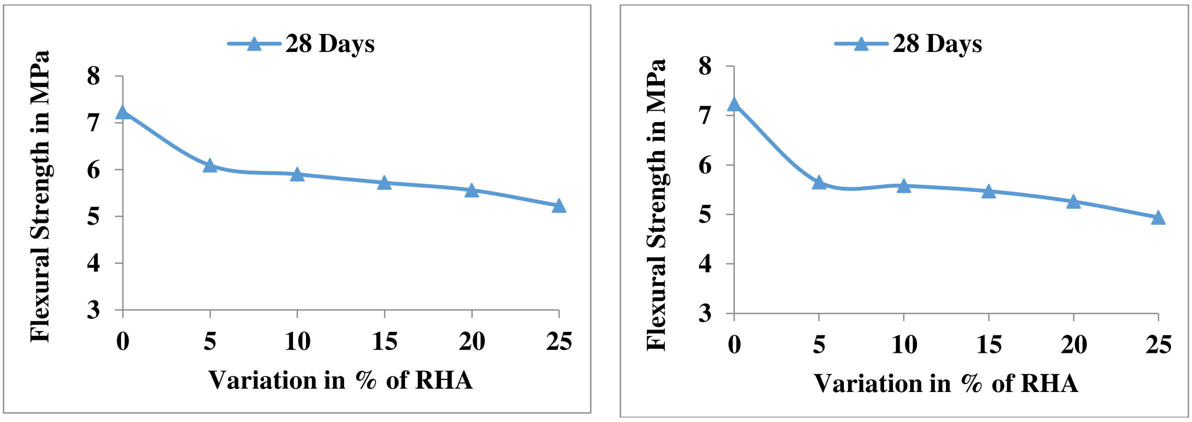
Figure3. Flexural Strength of ECC-RHA Specimens

The flexural strength of ECC control mix was 5.7 MPa, 6.01 MPa and 6.36MPa at 7, 14 and 28 days of curing respectively. On further experimental results, the flexural strength increased with the addition of fiber up to 1.5 % beyond which the addition of polypropylene fiber decreasedthe strength compared to all other mixes including control mix. The flexural strength of all the mixes showed near value between 5.43 MPa to 6.81 MPa. The percentage variation in flexural strength decreased when 10% RHA was replaced with addition of fiber from 0.5% to 2.0%.Thus, replacement of RHA did not show much effect in flexure when compared tocontrol mix.This failure in strength may be caused due to the effect of chemical composition of RHA.

Figure 4, shows the effect of 28 days flexural strength of ECC-RHA mixes corresponding to each percentage addition of polypropylene fibers.



a. 0.5% PolypropyleneFiber **b. 1.0% PolypropyleneFiber**

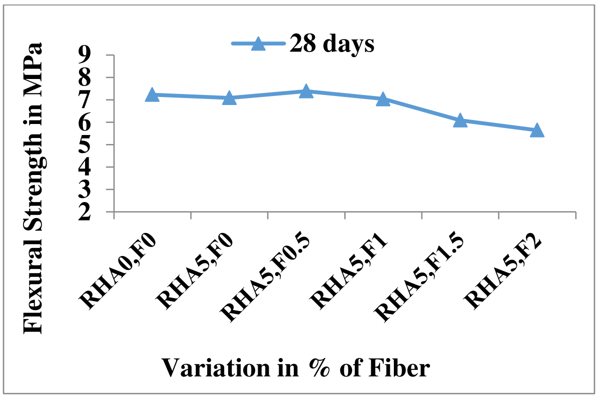


c. 1.5% PolypropyleneFiber **d. 2.0% PolypropyleneFiber**

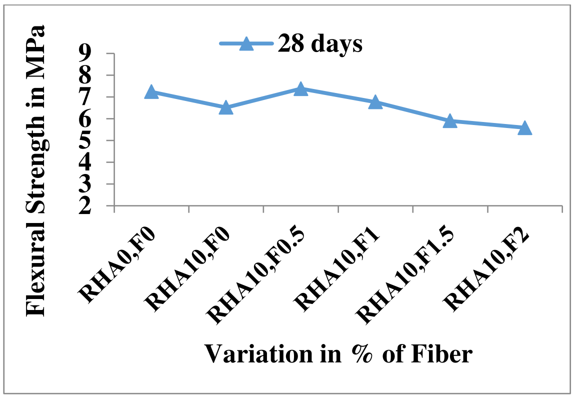
Figure 4. Variation in Flexural Strength of ECC-RHA Mixes w.r.t Fiber Addition

It can be inferred from Figure 4 that the flexural strength of ECC-RHA mixes was increasing upto 10% replacement of rice husk ash beyond which it started decliningin each percentage addition of polypropylene fibre. From these observations, it evinced that 10% replacement of rice husk ash was found to be optimum providing strength and good control over the mix.

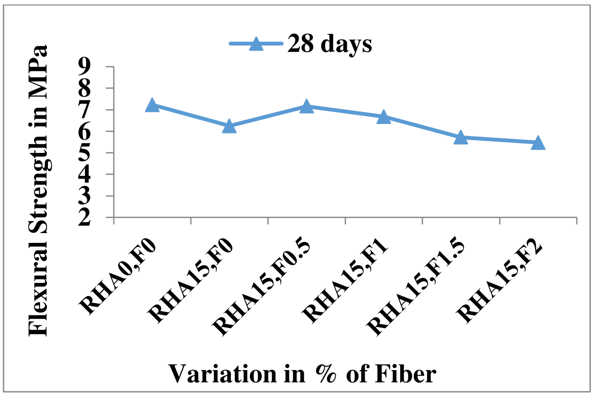
Figure 5, shows the effect of 28 days flexural strength of ECC-RHA mixes corresponding to each percentage replacement of rice husk ash cementitious mineral.



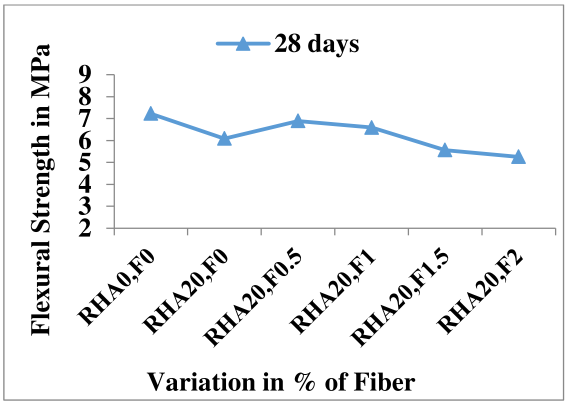
a. 5% RHA Replacement



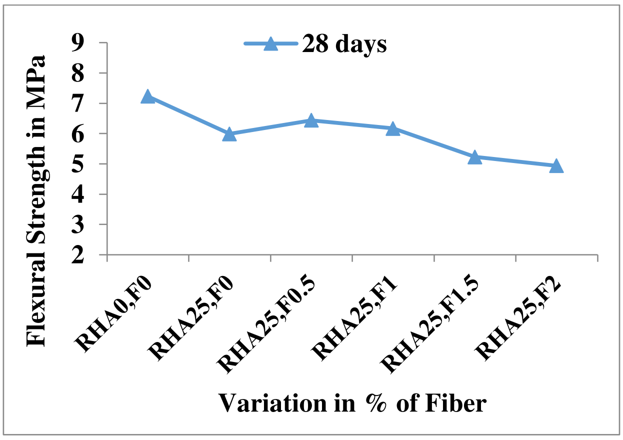
b. 10% RHA Replacement



c. 15% RHA Replacement



d. 20% RHA Replacement



e. 25% RHA Replacement

Figure 5. Variation in Flexural Strength of ECC Mixes w.r.t RHA Replacement

It can be inferred from Figure 5, that the flexural strength of ECC-RHA mixes was increasing upto 0.5% addition of polypropylene fiber beyond which it started declining in each percentage replacement of rice husk ash cementitious mineral.

2.3.2 Load-Deflection Relationship

Figure 6, demonstrates the load-deflection pattern of the of the optimized fibre reinforced ECC mix, RHA10-F0.5.

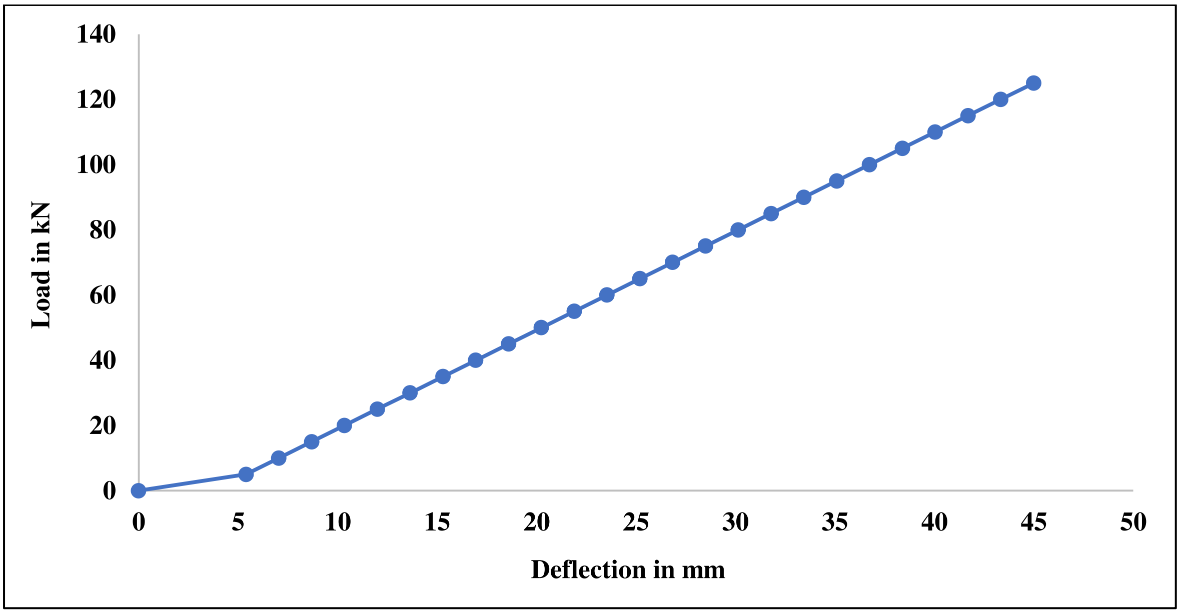


Figure 6. Load-Deflection Profile of Fibre Reinforced ECC-RHA Specimen

The load-deflection profile of the fibre reinforced ECC-RHA specimen of the RHA10-F0.5 mix showed a linear variation until its failure. At this instance, when the specimen was subjected to initial load, the composites tend to get elongated as a response in multi-direction. As a result, the specimen continued to acquire increase in load until yield point where the polypropylene fibres will resist and elongate until failure. The flexural failure occurred at a peak load of 125 kN corresponding to a maximum deflection of 45mm. The mode of failure of the prism was brittle due to the action of splitting tensile force and the line of fracture occurred at a distance nearer to thesupport.

3. FINITE ELEMENT ANALYSIS USING ANSYS

3.1 Simulation of the 3D Finite Element Model

Analysis systems (ANSYS) V-14.5 was used to estimate the tensile and flexural strength for the optimized engineered cementitious composites containing 10% rice husk ash and 0.5% polypropylene fibres. The sequence of activities carried out in finite element modelling are creating a separate database for the proposed coupon specimen, designing its geometry section in three-dimensional mode and modelling it with required specifications thereafter applying the boundary conditions confining to the degree of freedom such that the software will be able to extract the required parameters say damage, tensile and flexural properties.

Solid-65 element was used to model the coupon specimen describing that as engineered cementitious composite as it has the potential to undergo cracking in terms of crushing in compression and cracking in tension. The solid has 380 elements and 5460 nodes having multiple degrees of freedom in all the three directions say x, y and z. Analysis systems requires engineering data for the proposed model which is then fed into the software to carry out its assessment. At first, the cross section say 75mm and 50mm for the model has been created and extruded to the desired span length say 360mm considering it as a three dimensional model. Another solid element having surface area of 15000 mm^2 had been created and assigned as Impactor in which pressure at the rate of 5E^7 will be applied so that the impactor will transfer the pressure to the entire model. Prior to analysis the entire model had been meshed for 50mm (Figure 7). As the supports are assigned as fixed on either side of the model, the model will undergo deformation when the pressure is applied (Figure 8). In the post processing wing, true scale result outcomes (Table 4) in terms of von mises stress, equivalent elastic strain, maximum shear stress and total deformation will be obtained.

Table4.Input Specifications for the Proposed FE Model

S.	Description	Values	Unit
	Young’s Modulus	33462	MPa
	Bulk Modulus	18590	MPa
	Shear Modulus	13943	MPa
	Poisson Ratio	0.3	--
	Ultimate Compressive strength	45	MPa
	Ultimate Tensile strength	460	MPa

The meshing and application of pressure on the 3D simulated finite element model of the optimized ECC specimen RHA10-F0.5, is shown in Figures 7 & 8 respectively.

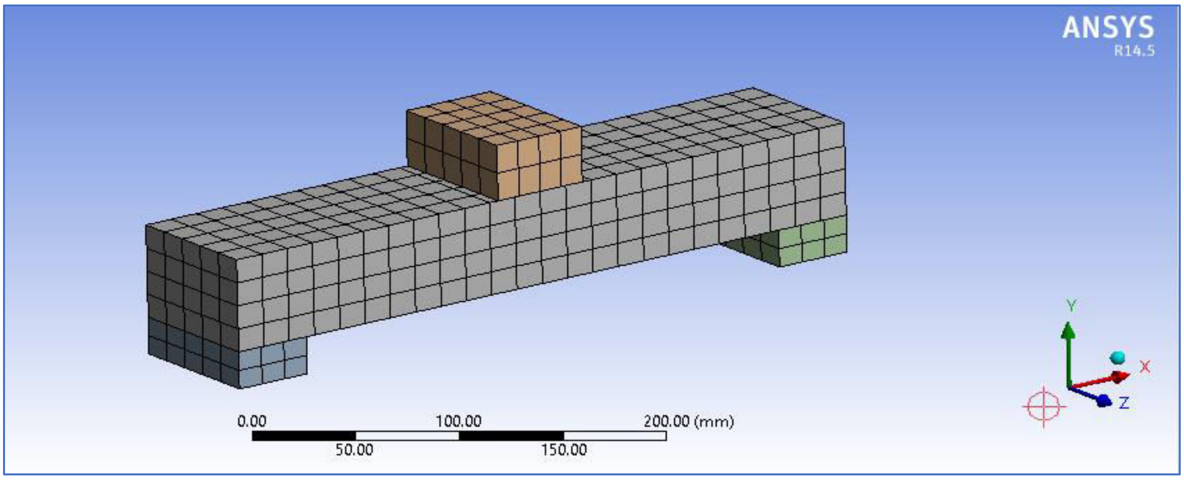


Figure 7. 3D-Meshing of the Optimized ECC Model RHA10-F0.5

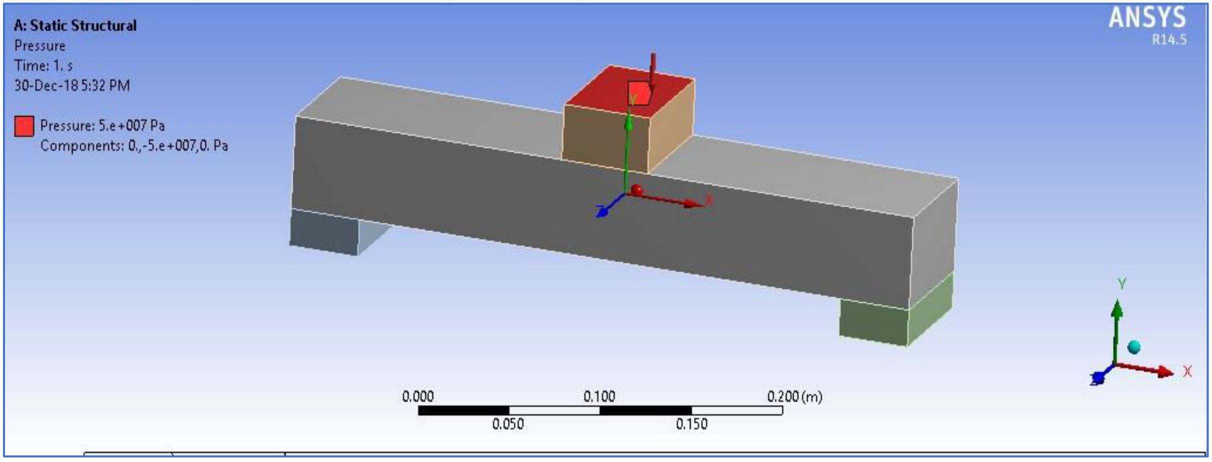


Figure 8.Applying Pressure on the OptimizedECC Model RHA10-F0.5

3.2 Post Processing Outcomes of the Finite Element Simulated Model

Figures 9 to 12 demonstrate the post-processing outcomes of the finite element analyses of the optimized ECC model RHA10-F0.5in terms of equivalent or Von-Mises stress, equivalent elastic strain, fracture at UY direction and total deformation.

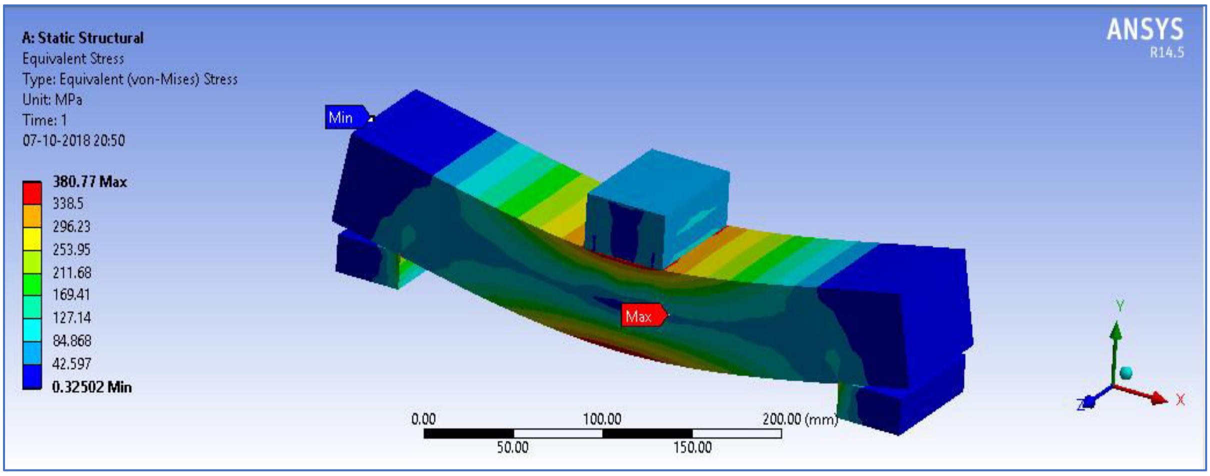


Figure 9.Equivalent (Von-Mises) Stress of the Optimized ECC Model RHA10-F0.5

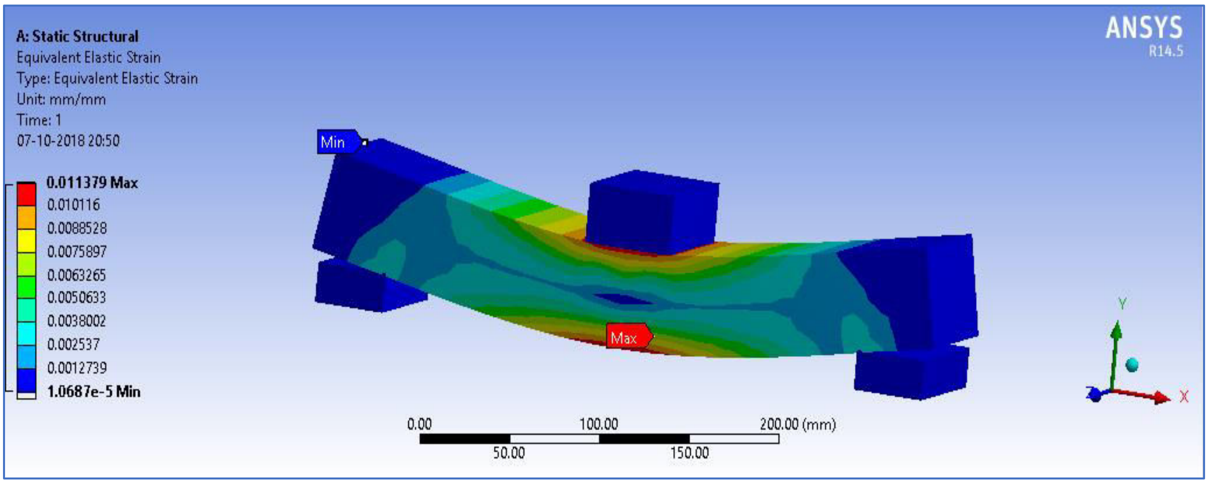


Figure 10.Equivalent Elastic Strain of the Optimized ECC Model RHA10-F0.5

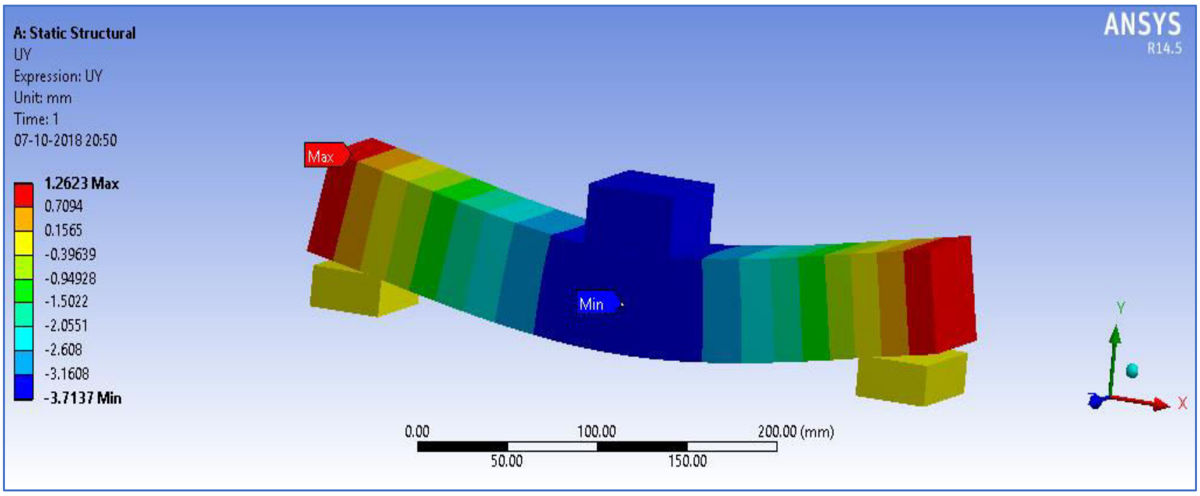


Figure 11.Fracture at UY Direction of the Optimized ECC Model RHA10-F0.5

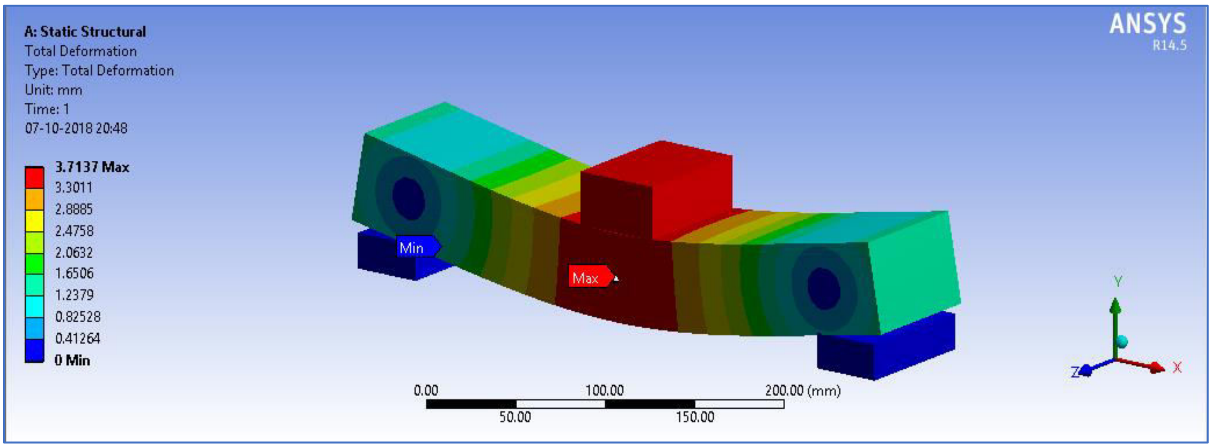


Figure 12. Total Deformation of the Optimized ECC Model RHA10-F0.5

The outcome of the flexural analysis of the finite element simulated ECC model RHA10-F0.5was obtained through the post processing analysis unit of the ANSYS software.From the FEM analysis, it was observed that the simulated ECC model RHA10-F0.5developed an equivalent stress (Von-Mises stress)to a minimum of 0.32502 MPa and maximum of 380.77 MPa, equivalent elastic strain to a minimum of 1.0687xE^-5 and maximum of 0.011379, displacement in U-Y direction to a minimum of -3.1737mm and maximum of 1.2623mm and total deformation to a maximum of 3.7137mm.

4. CONCLUSIONS

In this study, a detailed experimental investigation was carried out on the engineered cementitious composite mixesby varying the percentage replacement ofrice husk ashand percentage addition of polypropylene fibres. In addition, a finite element model was simulated on the optimized prism specimen to study its bending behaviour. Based on these investigations, the following conclusions on the flexural aspects of the fibre reinforced ECC specimens are drawn.

1. Among all the ECC-RHA mixes the optimized mix was found to be RHA10-F0.5.

2. The maximum 28 days flexural strength produced by this optimum ECC mix specimen RHA10-F0.5was 6.81 MPa.

3. The percentage variation of 28 days flexural strength of the optimum ECC mix specimen RHA10-F0.5with that of control specimen RHA0-F0 was 7.08%.

4. The load-deflection relationship of the optimum ECC mix specimen RHA10-F0.5was linear until its failure.

5. The failure mode of the optimum ECC mix specimen RHA10-F0.5was purely a splitting tensile failure.

6. The simulated model of optimum ECC mix specimen RHA10-F0.5using ANSYS software showed a good coherence with the experimental results.

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