Numerical Analysis on Strength Capacity of ECC Beams and Columns

Selvamole A[1], Binu P[2]

[1]*PG Student, Department of Civil Engineering, SNGCE, Kadayiruppu, Kerala, India*
[2]*Associate Professor, Department of Civil Engineering, SNGCE, Kadayiruppu, Kerala, India*

Abstract - *This study experimentally investigates the static analysis with full ECC beam and NC is conducted to evaluate the performance of ECC. Results from this analysis shows that ECC can withstand more load in comparison with normal concrete. It is followed with another analysis which comprises of different configurations of ECC. This study enquires about effectiveness of ECC with varying percentage and position. ECC on top configuration shows better load carrying capacity. A dynamic analysis is conducted to study about the energy absorption capacity of ECC during earthquake. From the hysteresis loop, absorption capacity of ECC is better than NC. A thermal analysis is also conducted to study about the effect of fire accidents. The stress developed in ECC is lower than NC which confirms that ECC is safe use in these situations. From all the analysis it is evident that ECC is a promising alternative.*

***Key Words*: Normal concrete; Engineered cementitious composite**

1. INTRODUCTION

Ordinary Portland cement, although expensive and energy consuming, is the most used ingredient in the production of concrete mixtures. Unfortunately, cement production itself involves the emission of large quantities of carbon dioxide into the atmosphere, a major contributor to the greenhouse effect and global warming. It is therefore inevitable to look for another material or to partially replace it with another material. The various investigations carried out by several authors in connection with the development of the Designed Cement Composite (ECC) and its applications in the real field prove to be one of the best alternative and sustainable concrete materials of the coming decades.

In terms of material components, ECC uses ingredients similar to those of fiber concrete (FRC). It contains water, cement, sand, fiber and some common chemical additives. Coarse aggregates are not used as they tend to adversely affect the unique ductile behavior of the composite. A typical composition uses a w / c ratio and a sand / cement ratio of 0.5 or less. Unlike some high performance FRCs, ECC does not use large amounts of fiber. In general, 2% or less by volume of staple fiber is adequate, even if the composite is designed for structural applications. Due to the relatively small amount of fiber and its chopped nature, the mixing process of ECC is similar to that used in mixing normal concrete. Also by deliberately limiting the amount of fiber, a number of proprietary studies have concluded the economic feasibility of ECC in specific structural applications.

1.1 Engineered Cementitious Composite

The Engineered Cement Composite (ECC), also known as Deformation-Curing Cement-based Composite (SHCC) or more commonly as collapsible concrete, is an easily moulded mortar-based composite reinforced with short random fibers specially selected, usually polymer fibers. Unlike ordinary concrete, ECC has a deformation capacity of around 3 to 7%, compared to 0.01% for paste, mortar or ordinary Portland cement concrete (OPC). ECC therefore acts more as a ductile metallic material than as a brittle glass material (as OPC concrete does), leading to a wide variety of applications. Bending performance of concrete beams containing engineering cement composites by Ali S. Shanour and. Al. Is experimentally studying the performance of ECC concrete beams reinforced with conventional rebar. In the article of experimental tests on the underwater abrasion of engineered cement composites by Sallal R. Abid et. A1. The abrasion of engineered cement composites (ECC) due to water-based materials in hydraulic structures was studied using the ASTM C1138 abrasion test method. The test pieces were divided into two groups, the first was studied to study the effect of the PVA fiber content, while the second studied the effect of the thickness of the ECC coating layer. An innovative hybrid engineering cement composite with crack healing capacity was launched in the study of the hybrid engineering cement composite reinforced by reinforced healing fibers (2017) by M.A.E.M. Ali and. Al. The mechanical properties of this composite, which incorporates short fibers of polyvinyl alcohol (PVA) and shape memory alloy (SMA) dispersed randomly, have been studied.

In the study of the bending behavior of composite steel beams coated with engineering cement composites by Zhang et. al., the bending behavior of a new form of composite steel beams covered with engineered cement composite (ECC) - light concrete (LWC) is studied. Four composite steel beams covered with simply supported ECC-LWC were tested to study the effects of the thickness of the ECC cover on ultimate load capacities and failure modes. To increase the durability and fire resistance of columns made of concrete filled steel tubes (CFST), CFST cement composite columns (ECC) were proposed in the document entitled Mechanical behavior of CFST recessed ECC columns subjected to a eccentric loading by Jingming Cai and. al. Seven CFST columns with ECC envelope with di ff erent parameters were tested, the parameters examined included the eccentricity ratio, the reinforcement ratio of the stirrup, the longitudinal reinforcement ratio and the thickness of the inner tube in steel. The Cement Composites study of advanced engineering with combined self-detection and self-healing functionalities by Hocine Siad and. Al. Focused on improving the self-detection capacity of engineered cement composites (ECC) to accurately monitor their cracking behavior and healing performance.

Engineering cement composite paper for effective reinforcement of RC beams in FRP by KS Leong presents the results of an experimental program designed to assess the performance of RC beams reinforced in FRP incorporating engineered cement composites (ECC) as a ductile layer around the main bending reinforcement.

2. RESEARCH METHODOLOGY

In the compression, the curve tension vs. deformation of the concrete is elastic and linear until nearly 30% of the last compression force. After this point, the concrete loses rigidity and follows elevating the tension values until rupture force. To model the concrete material, it is necessary to provide the program ANSYS the following input data: longitudinal elasticity module of the concrete; ultimate strength of the concrete to compression and traction; Poisson coefficient; and transfer coefficient of shear. The longitudinal elasticity module of the concrete, Ec, as well as, the concrete traction strength, ftk, were determined based in the recommendations of NBR 6118:2007. Poisson coefficient, ν, adopted to the concrete was equal to 0,2 and the shear transference coefficients, β adopted were equal to 1 to open and closed cracking. This value for the coefficient β was used, because tests performed showed bigger efficiency in the convergence of the processing when used the mentioned value.

Concrete rupture criterion provided by Ansys was used. For the definition of the rupture superficies it is necessary only two parameters: the strengths to the last compression and traction of the concrete. Concrete rupture criterion is analogue to William-Warnke rupture criterion.

2.1 Drucker-prager concrete

The DP model is a plasticity model that describes the behavior of granular materials in which the yield behavior is affected by the equivalent pressure stress. For loading in tension and tension-compression, the Drucker-Prager yield surface is:

$$f_{DP_t} = \frac{\sigma_e}{\sqrt{3}} + \beta_t \sigma_m - \sigma_{Y_t} \Omega_1$$

where β_t and σ_{Y_t} are constants defined by the uniaxial tensile strength R_t and uniaxial compressive strength R_c. The flow potential for yielding in tension and tension-compression is,

$$Q_{DP_t} = \frac{\sigma_e}{\sqrt{3}} + \delta_t \beta_t \sigma_m$$

The data regarding the normal concrete (NC) and engineered cementitious composite (ECC) obtained from literature are given in Table 2.1

Table -2.1: Data obtained from the journal

PROPERTY	SPECIMENS	
	NC	ECC
Young's modulus (GPa)	27.3	29
Poisson's ratio	0.2	0.2
Drucker Prager yield criteria c, $\sin\Phi$ and $\sin\Psi$	17.96, 0.1736, 0.1736	18.8, 0.1736, 0.1736
Tensile strength, f_{ct} (MPa)	3.41	3.43

Compressive strength , f'_c (MPa)	42.8	44.8
Tension softening Maximum tensile strain ε_s	0.003	0.003
Shear retention β	0.2	0.2

2.2 Kinematic Hardening

The yield criterion for many materials depends on the history of loading and evolution of plastic strain. The change in the yield criterion due to loading is called hardening and is defined by the hardening rule. Hardening behavior results in an increase in yield stress upon further loading from a state on the yield surface so that for a plastically deforming material, an increase in stress is accompanied by an increase in plastic strain.

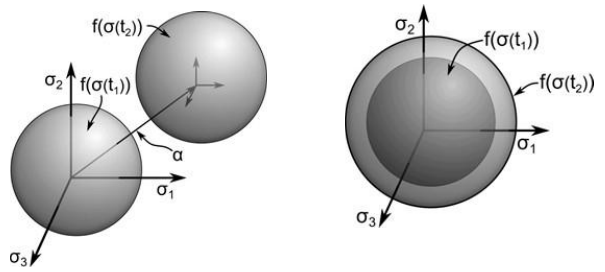


Fig - 2.1: Isotropic and Kinematic Hardening and yield surface

2.3 Von mises yield criterion

The von Mises yield criterion is commonly used in plasticity models for a wide range of materials. It is a good first approximation for metals, polymers, and saturated geological materials. The criterion is isotropic and independent of hydrostatic pressure, which can limit its applicability to microstructured materials and materials that exhibit plastic dilatation.

2.4 Elements used for the analysis

For the modeling of the concrete material, we used the finite element Solid 65. This element has eight nodes with three degrees of freedom per node – translations in the directions x, y and z. The element presents plastic deformations, cracking and crushing in three orthogonal directions. In the element Solid 65, the cracking occurs when the main stress of the traction in any direction reaches the rupture superficies. After the cracking, the elasticity module of the concrete has value equal to zero in the considered direction. The crushing occurs when all compression tensions reach the rupture superficies, subsequently, the elasticity module has value equal to zero in all directions. Figure 2.2 presents the element Solid 65.

In the modeling of the steel bars of the reinforcement it was used the finite element Link 180. This element has two nodes, so that each node has three degrees of freedom – translations in the directions x, y and z. Figure 2.3 shows this element. We chose this element, because the armors in the models were discrete.

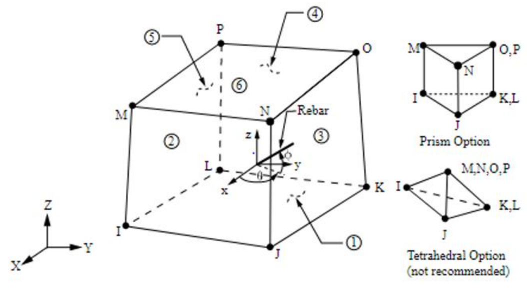


Fig -2.2: SOLID65 Geometry

In the models, it was not considered the phenomenon of the adherence between the steel bars and the concrete.

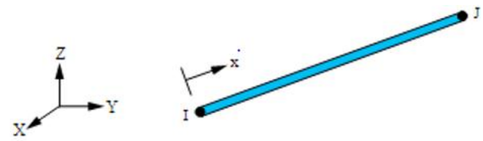


Fig -2.3: LINK180 Geometry

The finite elements of contact were used only in the models with smooth conformation of the walls of the precast and the column, because, due to researches already performed by several researchers, it can be considered that the link column-foundation through precast with shear key have monolithic behavior.

3. NUMERICAL ANALYSIS

3.1 Finite element analysis

Finite Element Analysis or FEA is the simulation of a physical phenomenon using a numerical mathematic technique referred to as the Finite Element Method, or FEM. The finite element method is the most widely used method for solving problems of engineering and mathematical models. Typical problem areas of interest include the traditional fields of structural analysis, heat transfer, fluid flow, mass transport, and electromagnetic potential.

3.1.1 Geometry used for the analysis

ANSYS 16 WORKBENCH is used to model concrete beam with bottom layered ECC. Figure 3.1 shows the geometric model of the beam.

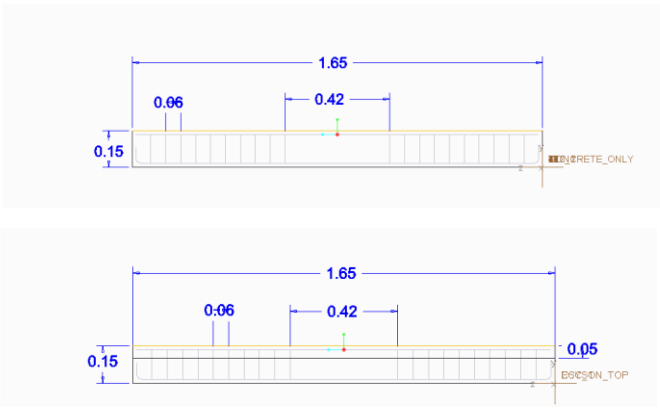


Fig -3.1: Beam with ECC two configurations

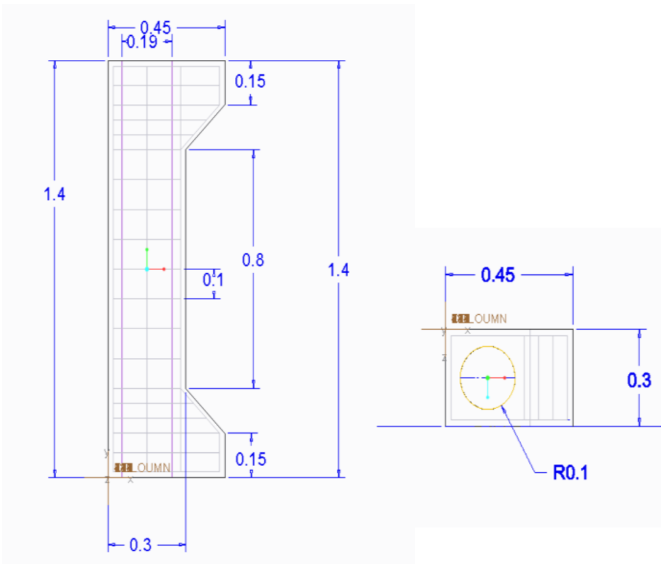


Fig -3.2: ECC encased CFST column

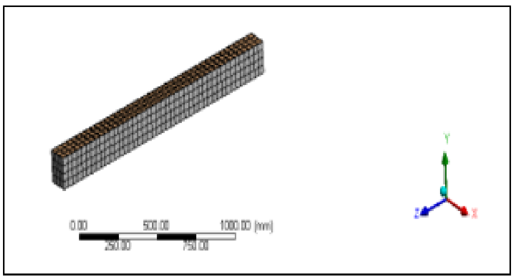
For all beams the longitudinal reinforcement consist of 3- 10 mm diameter deformed bars in tension zone and 2-10mm diameter deformed bars in compression zone. Shear reinforcement consist of 6mm plane bar stirrups spaced at 60mm c/c in the shear span and a clear cover of 15mm was used throught. The ECC layer was about one third of the total depth of the beam.

Concrete filled steel tube (CFST) columns have gained increasing attention over the last decades. A large amount of studies have been carried out on the performance of CFST columns under static and dynamic loading previously. It has been found that CFST columns have better structural performance than steel reinforced concrete (RC) columns in terms of ductility and load carrying capacity. However, despite its structural advantages, the outer steel tube of CFST is susceptible to corrosion especially under chloride environment. It has been found that corrosion caused significantly deterioration to the compressive and flexural strength of CFST column. Moreover, the fire resistance of CFST column has been a concern as the outer steel tube nearly loses its strength at 600°C.

In order to improve the durability and fire resistance of CFST composite column, the engineered cementitious composite (ECC) encased-CFST column is proposed. Fig. 3.2 shows the typical cross section of ECC-encased CFST column, which includes an inner CFST component and an outer reinforced ECC component. Ithasalsobeen observed that the mechanical performance of fire-deteriorated ECC material is better than that of conventional concrete and no explosive spoiling occurred in ECC specimens, since PVA fiber could introduce additional channels for vapourized moisture in ECC to escape without creating high internal pressure in the material. Due to its unique properties, ECC material has been successfully applied to structural members such as beams , columns, slabs and beam-column connections .

3.1.2 Mesh

Mesh Size for the concrete and rebar is 20mm. Mesh Size was decided after conducting a mesh convergence study. Bonding between concrete and rebar was made sure using node merge option in ANSYS Meshing. Concrete was modelled with SOLID65 and Rebar were modelled with LINK180.



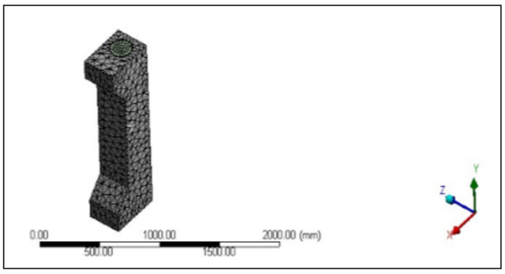


Fig -3.3: Mesh

3.1.3 Boundary conditions

Boundary conditions given to the beam and column are static loading and thermal loading respectively. Figures 3.4 and 3.5 shows the front and isometric view of the beam under static loading respectively.

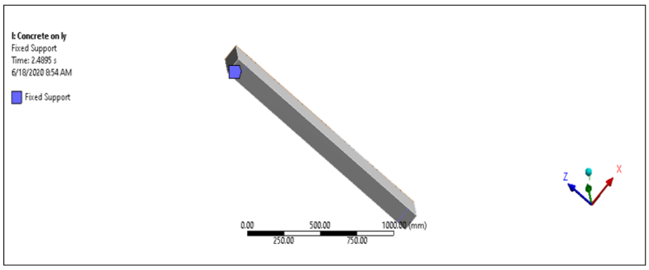


Fig- 3.4: Front view of the beam under static loading

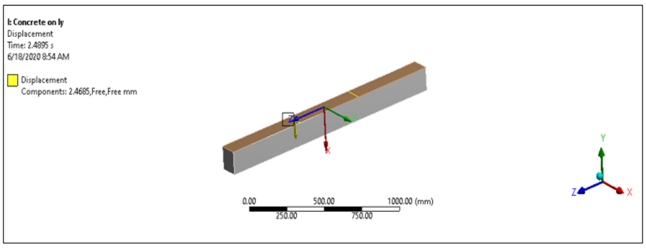


Fig -3.5: Isometric view of the beam under static loading

Boundary of the column is provided with 5000 W heat input. Figure 3.6 shows the thermal loading condition of the column.

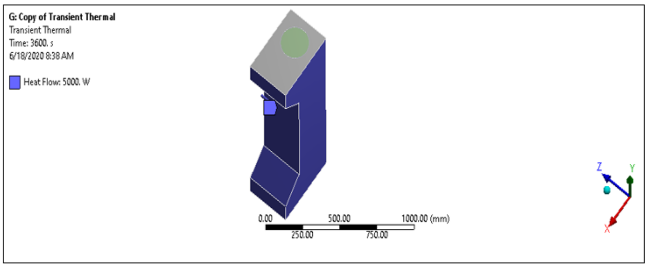


Fig -3.6: Thermal loading condition for column

Temperature distribution is the output of thermal analysis. This temperature distributions is used as an input for structural analysis. Figure 3.7 shows the temperature distribution in column.

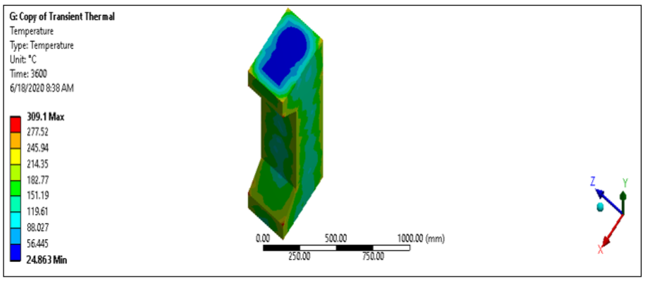


Fig -3.7: Temperature distribution in column.

4 RESULTS AND DISCUSSIONS

4.1 Static analysis

Static analysis of normal concrete beam , ECC beam, concrete beam with top layered ECC, concrete beam with bottom layered ECC concrete beam with top and bottom layered ECC and thermal analysis on ECC encased CFST column were done using the software ANSYS WORKBENCH. After analysis comparison between normal concrete beam and ECC beam were obtained. Comparison between beams with ECC on top, ECC on bottom and ECC on top and bottom were also obtained from the analysis.

4.1.1 Analysis of normal concrete beam

The total equivalent stress in the normal concrete beam is 34.785MPa.

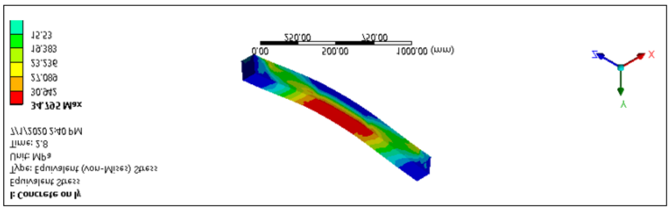


Fig - 4.1: Stress model of normal concrete beam

The total equivalent strain in the normal concrete beam is 0.0038766.

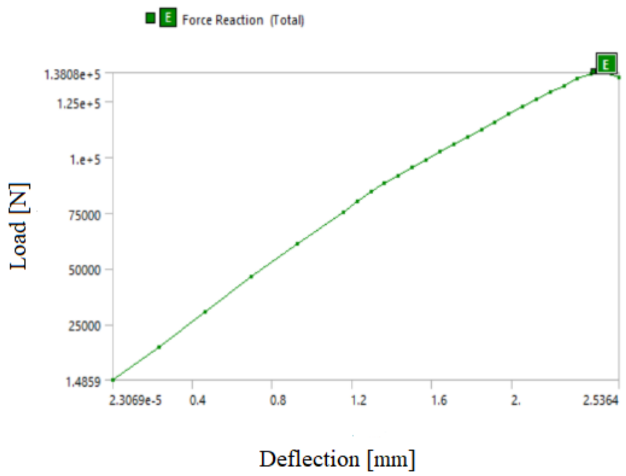


Fig- 4.2: Graph showing maximum load carrying capacity in mm where x axis shows deflection in mm and y axis shows load in N.

4.1.2 Analysis of ECC beam

The total equivalent stress in the ECC beam is 38.947MPa.

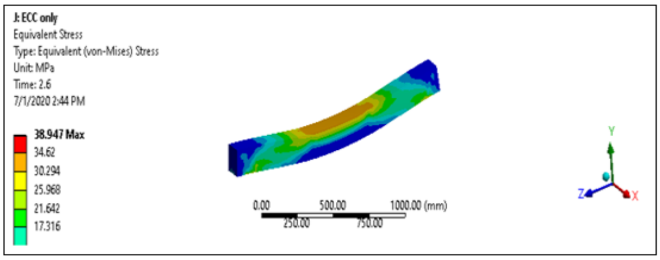


Fig- 4.3: Stress model of ECC beam

The total equivalent strain in the ECC is 0.0029334. The total maximum deflection on the ECC beam is 3.2394 mm. Maximum Load carrying capacity of ECC beam model is 153480N.

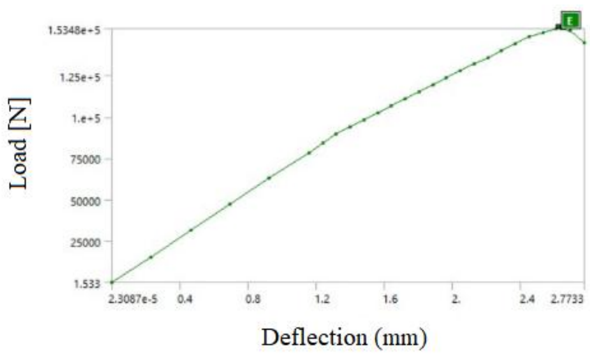


Fig -4.4: Graph showing maximum load carrying capacity in mm where x axis shows deflection in mm and y axis shows load in N.

4.1.3 Analysis of ECC (top) beam

The total equivalent stress in the ECC(top) beam is 33.086MPa.

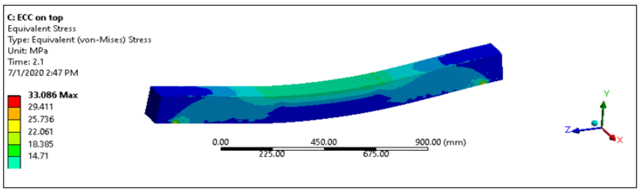


Fig -4.5: Stress model of ECC(top) beam

The total equivalent strain in the ECC(top) is 0.003431.The total maximum deflection on the ECC(top) beam is 1.2701 mm.Maximum Load carrying capacity of ECC(top) beam model is 65124N.

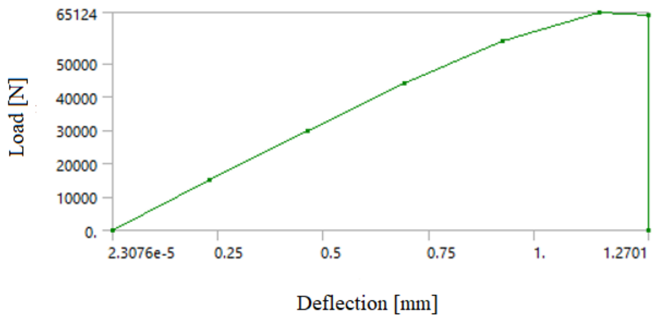


Fig- 4.6: Graph showing maximum load carrying capacity in mm where x axis shows deflection in mm and y axis shows load in N.

4.1.4 Analysis of ECC(top & bottom) beam

The total equivalent stress in the ECC(top & bottom) beam is 30.286MPa.

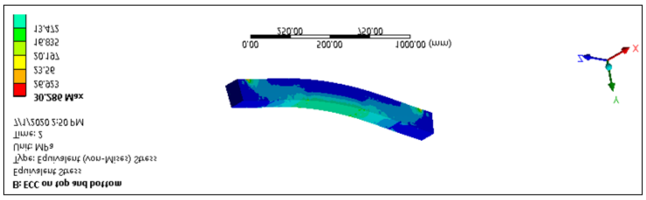


Fig- 4.7: Stress model of ECC(top & bottom) beam

The total equivalent strain in the ECC(top& bottom) is 0.0027981. The total maximum deflection on the ECC(top & bottom) beam is 1.1546 mm. Maximum Load carrying capacity of ECC(top & bottom) beam model is 50541N

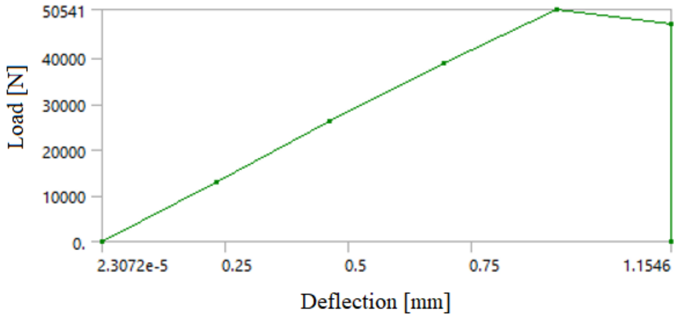


Fig- 4.8: Graph showing maximum load carrying capacity in mm where x axis shows deflection in mm and y axis shows load in N.

Table -4.1: Comparison between NC and ECC

Model	Max Stress in MPa	Total Strain in mm/mm	Total Deflection in mm	Max Load in Newton
NC	34.785	0.00387	3.9289	138080
ECC	38.947	0.00293	3.2394	153480

Table 4.1 shows the comparison between normal concrete beam and ECC beam. From the table we can understand that the load carrying capacity of ECC is better than normal concrete beam. ECC beam can withstand large amount of tensile force.

Table- 4.2: Comparison between ECC layered concrete at bottom top and top & bottom.

Model	Max Stress in MPa	Total Strain in mm/mm	Total Deflection in mm	Max Load in Newton
ECC-Concrete Hybrid(Bottom)	28.292	0.00311	3.9321	60618
ECC-Concrete Hybrid(Top)	33.086	0.003431	1.2701	65124
ECC-Concrete Hybrid(Top & Bottom)	30.286	0.0027981	1.1546	50541

Table 4.2 shows the comparison between beams with ECC layer at top, bottom and top & bottom. Beam with ECC layer at top shows more load carrying capacity than the other beams.

4.2 Dynamic analysis (cyclic loading)

Cyclic loading is the application of repeated or fluctuating stresses, strains, or stress intensities to locations on structural components. The degradation that may occur at the location is referred to as fatigue degradation. Cyclic loading, which includes inertial loadings developed by environmental conditions such as storm waves and earthquakes, can have two potentially counteractive effects on the static axial capacity. Repetitive loadings can cause a temporary or permanent decrease in load-carrying resistance or an accumulation of deformation. Rapidly applied loadings can cause an increase in load-carrying resistance or stiffness of the column. Very slowly applied loadings can cause a decrease in load-carrying resistance or stiffness of the column. Fig 6.17 shows the pattern of cyclic displacement loading given to the normal concrete and ECC beam. The displacement given to the beam are 0,2,-2,4,-4,6,-6,8 etc.

The figure 4.9 shows the hysteresis loop obtained as a result of cyclic strain controlled loading given to the normal concrete beam. The figure 4.10 shows the hysteresis loop obtained as a result of cyclic strain controlled loading given to the ECC beam. By comparing these two loops we can understand that the loop area of ECC beam is more than that area of concrete beam. The more area indicates that the energy dissipation is higher for ECC beam. Hence the ECC is better for withstanding cyclic loading than the normal concrete beam.

4.3 Thermal analysis

Boundary of the column is provided with 5000 W heat input. Temperature distribution is the output of thermal analysis. These temperature distributions are used as an input for structural analysis. Figure 4.11 shows the temperature distribution in column with respect to time.

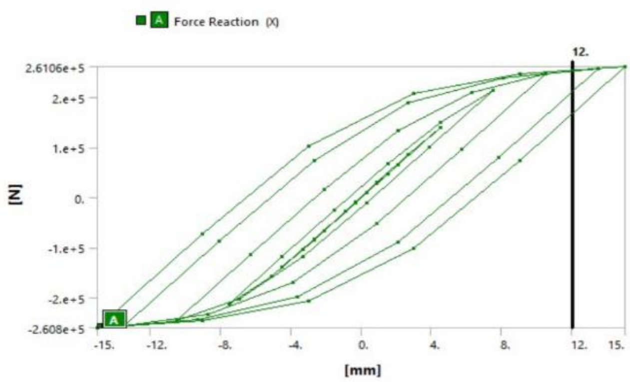


Fig -4.9: Hysteresis loop obtained for normal concrete beam

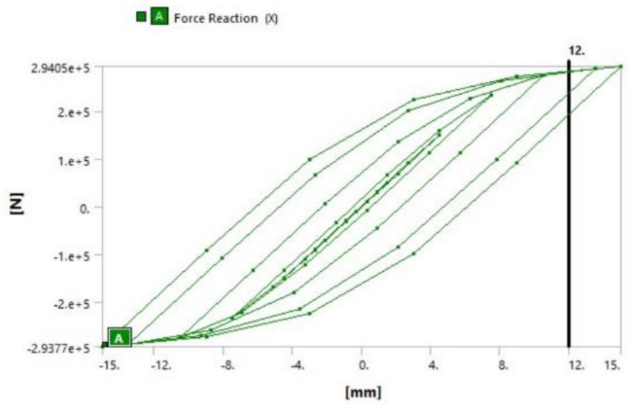


Fig- 4.10: Hysteresis loop obtained for ECC beam

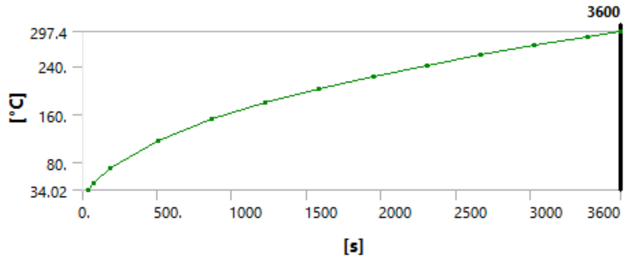


Fig- 4.11: Temperature distribution with respect to time.

The maximum equivalent stress obtained for normal concrete column is 41.032MPa.

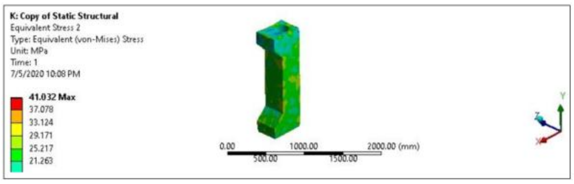


Fig- 4.12: Equivalent stress on normal concrete column

The maximum equivalent strain obtained for normal concrete column is 0.003635.

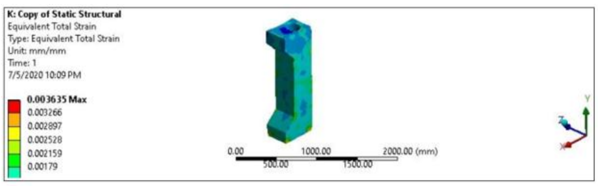


Fig- 4.13: Equivalent strain on normal concrete column

The total deformation obtained for normal concrete column is 1.4447mm.The total equivalent stress on ECC column is 34.861MPa.

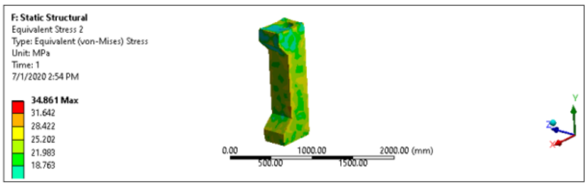


Fig- 4.14: Equivalent stress on ECC column

The total equivalent strain on ECC column is 0.0036317. The total deflection obtained for ECC column is 1.5524mm. Table 4.3 shows a comparative study between normal concrete column and ECC column.

Table- 4.3: Comparative study between NC & ECC column

Model	Max Stress in MPa	Total Strain in mm/mm	Total Deflection in mm
NC	41.032	0.003635	1.4447
ECC	34.861	0.003632	1.5524

Table 4.3 shows maximum stress occurred in the column after the thermal analysis. An electric fire is simulated with 5000 W heat source. Expansion of concrete will happen due the elevated temperature at various points of concrete. The von mises stress criterion is used here to find out the failure of column. The equivalent stress developed in normal concrete (41.032 MPa) is more than ECC (34.861 MPa). From the table both NC and ECC are safe during the fire, but equivalent stress of NC is very near to its compressive strength. The equivalent stress of ECC is far below than its compressive strength. Hence it is evident that ECC shows a remarkable performance in comparison with NC

5. CONCLUSIONS

The objective of engineered cementitious composites is to develop a robust and flexible material that can be utilized in various purpose where fiber reinforced concrete can't be used. It is the newest concept. The formation of cementitious materials with high ductility is useful for structural applications. The engineered cementitious composites contain properties of high strength concrete having improved tensile strain capacity. The results of the studies highlighted provides confidence in the widening use of ECC in a broad range of new concrete structures.

Static analysis with full ECC beam and NC is conducted to evaluate the performance of ECC. Results from this analysis shows that ECC can withstand more load in comparison with normal concrete. It is followed with another analysis which comprises of different configurations of ECC. This study enquires about effectiveness of ECC with varying percentage and position. ECC on top configuration shows better load carrying capacity. A dynamic analysis is conducted to study about the energy absorption capacity of ECC during earthquake. From the hysteresis loop, absorption capacity of ECC is better than NC. A thermal analysis is also conducted to study about the effect of fire accidents. The stress developed in ECC is lower than NC which confirms that ECC is safe use in these situations. From all the analysis it is evident that ECC is a promising alternative.

purus lectus malesuada libero, sit amet commodo magna eros quis urna. Nunc viverra imperdiet enim. Fusce est. Vivamus a tellus. Pellentesque habitant morbi tristique senectus et netus et malesuada fames ac turpis egestas.

REFERENCES

[1] Ali S. Shanour et. al "Flexural performance of concrete beams containing engineered cementitious composites", Construction and Building Materials 180 (2018) 23–34, Elsevier.

[2] Sallal R. Abid et. al "Experimental tests on the underwater abrasion of Engineered Cementitious Composites", Construction and Building Materials 171 (2018) 779Ð792 , Elsevier.

[3] M.A.E.M. Ali et. al "Innovative crack-healing hybrid fiber reinforced engineered cementitious composite", Construction and Building Materials 150 (2017) 689–702, Elsevier.

[4] Zang et. al "Flexural behaviour of steel composite beams encased by engineered cementitious composites", Journal of Constructional Steel Research 143 (2018) 279-290, Elsevier.

[5] Jingming Cai et. al "Mechanical behavior of ECC-encased CFST columns subjected to eccentric loading", Engineering Structures 162 (2018) 22–28, Elsevier.

[6] Hocine Siad et. al "Advanced engineered cementitious composites with combined self-sensing and self-healing functionalities", Construction and Building Materials 176 (2018) 313Ð322, Elsevier.

[7] K.S Leong et. al. "Engineered cementitious composite for effective FRP strenghthening of RC beams" , Composites Science and Technology 65 (2005) 1120–1128, Elsevier.

[8] Yi Huang et. al "Self-sensing properties of Engineered Cementitious Composites", Construction and Building Materials 174 (2018) 253–262, Elsevier.

[9] Xu Yang et. al "Flexural strengthening of RC beams with CFRP grid-reinforced ECC matrix", Composite Structures 189 (2018) 9–28, Elsevier.

[10] Kequan Yu et. al "Direct tensile properties of engineered cementitious composites: A review", Construction and Building Materials 165 (2018) 346–362 , Elsevier.