M.Tech Dissertation Report

Submitted in partial fulfilment for the award of Degree of.
Master of Technology (M. Tech)
Structural Engineering

Topic

To Study the flexural behavior of Engineered Cementitious Composites Beams

BY

AKHIL SRIVASTAVA
M. Tech (STRUCTURAL ENGINEERING)
Roll No.: 1801431018

–

Under The Guidance of

Mr. Mohd Kashif Khan
Associate Professor
Department Of Civil Engineering.

Integral University, Lucknow
Polytechnic / Faculty of Engineering / Faculty of Management & Research / Faculty of Pharmacy
Web : www.integraluniversity.ac.in

2019-2020

DECLARATION

I declare that the research thesis entitled "***To Study the flexural behavior of Engineered Cementitious Composites Beams***" is the bonafide research work carried out by me, under the guidance of **Mr. Mohd Kashif Khan, Associate Professor, Department of Civil Engineering, Integral University, Lucknow**.

Further I declare that this has not previously formed the basis of award of any degree, diploma, associate-ship or other similar degrees or diplomas, and has not been submitted anywhere else.

Date: 10/11/2020
Place: Lucknow

AKHIL SRIVASTAVA

Roll No.1801431018
Department of Civil Engineering,
Integral University, Lucknow

CERTIFICATE

Certified that the thesis entitled ***"To Study the flexural behavior of Engineered Cementitious Composites Beams"*** *is being submitted by* ***Mr. Akhil Srivastava (Roll No. 1801431018)*** *in partial fulfillment of the requirement for the award of degree of Master of Technology (Structures) of Integral University, Lucknow, is a record of candidate's own work carried out by him/her under my supervision and guidance.*

The results presented in this thesis have not been submitted to any other university or institute for the award of any other degree or diploma.

Mr. Mohd Kashif Khan

Associate Professor

Department of Civil Engineering

Integral University, Lucknow

ACKNOWLEDGEMENT

First I wish to express my sincere gratitude to my supervisor Mr. Kashif Khan for his enthusiasm, patience, insight, comments, helpful information and practical advice that has helped me in completing my research **“To Study the flexural behavior of Engineered Cementitious Composites Beams” s**uccessfully.

I would also like to thank to **Dr. Syed Aqeel Ahmad, Professor and Head of Department Civil Engineering** for his encouragement during the Project. I would also like to thank to all the faculty staff of Civil Engineering department.

AKHIL SRIVASTAVA
1801431018
Department of Civil Engineering
Integral University

List of Tables

1. Physical properties of ECC
2. Beam Design Data for Simply Supported Beams
3. Beam Design Data for fixed beams
4. Specimen Mixture
5. Total Deflection in the beam after the analysis (Fixed Beams)
6. Total Deflection in the beam after the analysis (Simply supported Beams)
7. Deflection vs Stresses
8. Deflection Under impact loading
9. Deflection due to Elevated Temperature

List of Abbreviations

1. ECC –Engineered Cementitious Composites
2. SHCC- Strain Hardening Cement Composites
3. PVA- Poly Vinyl Alcohol
4. SMA- Shape Memory Alloy
5. FEA- Finite Element Analysis
6. HPFRC- High-performance Fiber-reinforced Concrete
7. FRC- Fiber Reinforced Concrete
8. SCC- Self Compacting Concrete
9. HRWRA- High Range Water Reducing Agent
10. HSC- High Strength Concrete

CHAPTER-1 INTRODUCTION

In this study flexural behavior of Engineered Cementitious Composites And concrete Beams using ANSYS software method.

Under which I will find out the flexural behavior, impact loading and elevated temperature conditions of ecc beam Composite beam.

Data will be used by experimental works from previous literatures and also will be used in performing the analysis of ANSYS software.

Modulus of elasticity of concrete (E_c) is defined as the ratio of the applied stress to the corresponding strain. Not only does it demonstrate the ability of concrete to withstand deformation due to applied stress but also its stiffness. In other words, it reflects the ability of concrete to deflect elastically. Modulus of elasticity of concrete is sensitive to aggregate and mixture proportions of concrete.

In the design of concrete structures, modulus of elasticity is considerably important that requires to be defined. The linear analysis of elements, which is based on elastic theory, is used in some cases to satisfy requirements of ultimate and serviceability limit state such as in the design of pre-stressed concrete structures.

Common applicable codes around the world such as ACI Code, European Code, British Standards, Canadian standard association, and Indian standard have provided a formula for the computation of elastic modulus of concrete.

Concrete modulus of elasticity based on Indian standard can be calculated using the following expression:

$$E_c = 5000\sqrt{f_{ck}}$$

Engineered Cementitious Composite (ECC), also called Strain Hardening Cement-based Composites (SHCC) or more popularly as **bendable concrete**, is an easily molded mortar-based composite reinforced with specially selected short random fibers, usually polymer fibers. Unlike regular concrete, ECC has a strain capacity in the range of 3–7%,compared to 0.01% for ordinary portland cement (OPC) paste, mortar or concrete. ECC therefore acts more like a ductile metal like material rather than a brittle glass like material (as does OPC concrete), leading to a wide variety of applications.

Engineered Cementitious Composite commonly known as ECC, as ECC, developed in the last decade may prove a safer, more durable, and sustainable concrete material which is environmental friendly, cost-effective and constructed with conventional construction equipment. Only with less than two percent by volume of short fibres, ECC has been developed these days. ECC is ductile in nature. Under flexure, normal concrete fractures in a brittle manner. In contrast, very high curvature can be achieved for ECC at increasingly higher loads, much like a ductile metal yielding. The tensile strain capacity of ECC can reach between 3 and 5 percent compared to 0.01 percent for normal concrete. Structural designers have found the damage tolerance and inherent tight crack width control of ECC. This behaviour of strain hardening is attracting its potentiality in structural applications. It has wide applications and scope in various fields of Civil Engineering.

Major physical properties of ECC

Compressive Strength (MPa)	First Crack Strength (MPa)	Ultimate Tensile Strength (MPa)	Ultimate Tensile Strain (%)	Young’s Modulus (GPa)	Flexural Strength (MPa)	Density (g/cc)
20-95	3-7	4-12	1-8	18-34	10-30	0.95-2.3

Ansys is a finite element analysis software used to simulate engineering problems. The software creates simulated computer models of structures, to simulate strength, toughness, elasticity, and other attributes. Ansys is used to determine how a product will function with different specifications, without building test products or conducting crash tests. Most Ansys simulations are performed using the Ansys Workbench software, which is one of the company's main products. Typically, Ansys users break down larger structures into small components that are each modelled and tested individually. A user may start by defining the dimensions of an object and then adding weight, pressure, temperature and other physical properties. Finally, the Ansys software simulates and analyses movement, fatigue, fractures, fluid flow, temperature distribution, electromagnetic efficiency and other effects over time.

Ansys also develops software for data management and backup, academic research and teaching. Ansys software is sold on an annual subscription basis.

ANSYS structural analysis software enables you to solve complex structural engineering problems and make better, faster design decisions. With the finite element analysis (FEA) solvers available in the suite, you can customize and automate solutions for your structural mechanics problems and parameterize them to analyse multiple design scenarios. You can also connect easily to other physics analysis tools for even greater fidelity. ANSYS structural analysis software is used throughout the industry to enable engineers to optimize their product designs and reduce the costs of physical testing.

Important unique properties of ECC :

- Able to bend like a metal, non-brittle and up to 40 % lighter.
- 500 times more resistant to cracking.
- Reduces or eliminates steel reinforcement.
- Minimizes maintenance cost and reduces environmental impacts.
- Faster precast or on-site construction.

CHAPTER-2 OBJECTIVES

1. To Study the flexural behavior of Engineered Cementitious Composites Beams using ANSYS Software Method.
2. To study the performance of ECC layered beam under impact loading.
3. To study the performance of ECC layered beam under elevated temperature.

CHAPTER-3 LITERATURE REVIEW

Ali S. Shanour et al. (2018) experimentally investigated the performance of ECC concrete beams reinforced with conventional reinforcement bars. Advanced Polyvinyl Alcohol Engineered Cementitious Composite (PVA-ECC) fibers were selected for this purpose. Twelve RC beams were poured and tested to study flexure behavior under four-point loading test. Two different longitudinal reinforcement percentages, variable volume ratios of (PVA) and polypropylene fibers (PP) were used.

Their Results concluded that ECC fibers in form of PVA exhibits much better behavior than discrete fibers in the form of polypropylene PP. The maximum load increases as the volume content of fibers increases. They revealed that ECC materials improve the behavior more significantly at low reinforcement ratios, ECC materials exhibits an improvement in ductility and reaches their extreme strength in the post- cracking deformation regime in addition to a relatively large inelastic deformation capability. Using limited layer thickness of PVA concrete (100 mm thickness layer of the cross section), ductility increases by 32% and 13% for a mix of PVA and PP fiber content ratios of 0.5% and 1.0%, respectively.

Bashar S. Mohammed et al. (2016) studied Structural Behaviour of Reinforced Self-Compacted Engineered Cementitious Composite Beams with different steel reinforcement ratios were designed, prepared, cast, cured, and tested to failure at the age of 28 days. They used ECC and found Engineered cementitious composite (ECC) is a special class of HPFRCCs, Unlike HPFRCCs, ECC requires much lower fibers, not greater than 2% volume fraction of polymeric fibers for comparable mechanical properties. ECC has high tensile strength from 4 to 6 MPa and large strain capacity between 3% and 5% and also exhibits high ductility by optimizing the microstructure of the composite. The experimental results were compared with theoretical values predicted using EC2, RILEM, and VecTor2 models. Results shown that failure modes in flexure and shear of R-SC-ECC beams are comparable to that of normal reinforced concrete beam. They concluded that R-SC-ECC fall in the category of ductility class medium to high which gives advantages of using R-SC-ECC beams in regions susceptible to seismic activities.

Bensaid Boulekbache et al. (2012) carried out experimental study to examining the influence of the paste yield stress and compressive strength on the behaviour of Fibre Reinforced Concrete (FRC) versus direct shear. The parameters studied are the steel fibre contents, the aspect ratio of fibres and the concrete strength. Prismatic specimens of dimensions 10 * 10 * 35 cm made of concrete of various yield stress reinforced with steel fibres hooked at the ends with three fibre volume fractions (i.e., 0%, 0.5% and 1%) and two aspects ratio (65 and 80) were tested to direct shear. Three types of concretes with various compressive strength and yield stress were tested, an Ordinary Concrete (OC), a Self-Compacting Concrete (SCC) and a High Strength Concrete (HSC). The concrete strengths investigated include 30 MPa for OC, 60 MPa for SCC and 80 MPa for HSC. The results show that the shear strength and ductility are affected and have been improved very significantly by the fibre contents, fibre aspect ratio and concrete strength. As the compressive strength and the volume fraction of fibres increase, the shear strength increases. The ductility was much higher for ordinary and self-compacting.

Dr.A.W.Dhawale et al reported that the cost of ECC is almost 3 times the cost of normal concrete hence it was generally not used for mass construction works , hence the test was conducted for the development of ECC in the mix design ratio of cement :sand : fly ash in the range of 1:1:1 and fibres by 1.2%. and they casted the cubes ,cylinders and beams for determining compressive, tensile capacity and flexural behaviours of the specimens according to IS standards and are cured in water for 7,14 and for 28 days .The test were indicted improvement in compressive ,tensile and flexural behaviour compared with the normal concrete mixes hence they found the suitable mixes that can be incorporated for large volume structural applications without loss of any ductility.

Dr.M.Rame Gowda, Ms Uma Devi et al reported that the ECC was developed and here the PVA fibres are used, the percentile of fibres was varied from 1.2% to 2.2% in the interval of 0.2%. In the experimental programme the ECC was prepared for two different mineral ad mixtures such as fly ash and rice husk ash. The beam specimens were casted for size of 304.8mmx76.2mmx12.2mm for a particular mix of PVA and different ad mixtures and were cured by poly ethylene sheet covered for 48 hrs, and then water cured for 14, 28 and 56days and mainly tested for flexure .They found controlled mixes show no deflections whereas fly ash based mix with the fibre content of 1.4% resulted in best load carrying capacity and with maximum deflections, whereas the rice husk based mix was resulted in taking up very less load and deflections.

En-Hua Yang et.al, in their study included four factors like Class C Fly ash ratio to Class F Fly ash ratio, water to binder ratio, amount of High-range water reducer and amount of Viscosity Modifying Admixture to investigate the composition effects on fresh and hardened properties of ECC. Among the four factors, water to binder ratio has the greatest effect on Plastic Viscosity. The plastic viscosity of fresh ECC has a significant impact on ECC tensile properties. The tensile strain and ultimate tensile strength of ECC were found to increase with the increase of plastic viscosity.

Jayne Marks, Jon Conklin reported that concrete is one which extremely accepted as vital component of today's society and is being used in various and different infrastructures that are very critical for the flawless and comfortable function of the world. Due to the property of very strong in compression yet comparably weak in tensile nature of cement concrete resulted in Fiber Reinforced Concrete, very little can be done in terms of load bearing and high tensile strains applications. Engineered Cementitious Composite solves the resulting problems and provides even more better advantages in application through its unique and distinctive properties of self-healing, high, tensile strength and ductility where tensile strength is almost 500 times that of standard concretes. Application of ECC on the commercial level resulting benefits are many, based on the concept that the standard repair cost structural life cycle has increased dramatically, the superior compressive strength of the concrete can possibly improve the structural integrity of the structures it's used in, and average maintenance cost and time as a whole is decreased. This not only improves durability and safety, but also cuts down on cost of materials used for maintenance of structures which in turn decrease negative impact on environment. The initial investing cost may be high results in proposal of an alternate to the general use of Engineered Cementitious Composite, however the long term savings from its application, will surpass initial expense that occur. Experimentation with Engineered Cementitious Composite is latest innovation on-going, and the fields of application are tremendous and forever expanding for Engineered Cementitious Composite. The seemingly exciting characteristics of this bendable, self-repairing concrete are being proven to be more and more applicable to society as application and testing continues, and in the future, the Engineered Cementitious Composite is going to become more prevalent in commercial concrete projects.

Jun Zhang et al. (2013) carried out an experimental study on the potential applications of the fibre reinforced engineered cementitious composite with characteristic of low drying shrinkage (LSECC) in concrete pavements for the purpose of eliminating joints that are normally used to accommodate temperature and shrinkage deformation. It was found that a composite slab containing both plain concrete and LSECC, with steel bars at the LSECC/concrete interface, and designed construction procedures, it is possible to localize the tensile cracks into the LSECC strip instead of cracking in adjacent concrete slab. The crucial problem that interfacial failure in composite slab was prevented by using reinforcing bars across the interfaces. Due to the strain-hardening and high strain capacity of the LSECC, the overall strain capacity and the integrity of the composite slab can be significantly improved. The temperature and shrinkage deformations can be accommodated by adequate selection on the length ratio of LSECC strip and concrete slab.

Jin-Keun Kim et al. (2007) has evaluated tensile and dispersion performance of ECC produced with ground granulated blast furnace slag. They used water-binder ratios (W/B) of 60%, 48%, 38%, 35% and 28% to measure the fiber /matrix interfacial properties and the fracture toughness of the mortar mix. The results show that both ductility and tensile strength of the Slag-ECC were measured to be significantly higher than these values for the ECC without slag. The use of slag particles should be useful for achieving strain-hardening behaviour. Although the toughness ratio decreases with the addition of slag particles at an identical W/C (60%), the tensile strain capacity of Slag-ECC is approximately 50% higher than that of ECC without slag. The contribution of slag particles in ECC improves workability.

Li-li Kan et al. (2012) investigated self-healing behaviour of ECC materials. Crack characteristics of M45-ECC and HFA-ECC specimens pre loaded to strain levels of 0.3%, 0.5%, 1.0%, 2.0% were investigated. This was done at different ages, resonant frequency and mechanical recovery behaviours of re-healed ECC materials, new crack paths after reloading and the chemical analysis of healing products. Based on the experimental results, ECC with multiple micro-cracks benefits self-healing behaviour. Longer aged samples and high fly ash contribute to create more cracks of smaller width. Ultimate tensile strength and tensile strain capacity of the majority ECC specimens at reloading are higher than the control specimens without cracks.

Mustafa Sahmaran and Victor Li in their investigation have given out the following materials and mix proportions for the following two ECC mixtures with Fly ash to Portland cement (FA/PC) of 1.2 and 2.2 by weight. This ratio was used in their investigation. The ECC mixtures were prepared in a standard mortar mixer at a constant amount of cementitious material and constant water to cementitious material ratio of 0.27. High Range water Reducer was added to the mixture until the desired ECC characteristics in its fresh state were visually observed. The cement used was Ordinary Portland Cement and Fly ash used was Class F Fly ash. The PVA fibers of tensile strength 1620 MPa and Elastic Modulus of 42.8 GPa were used in the mix proportion.

Mustafa Sahmaran et al. (2013) carried out experimental work for 36 different ECC mixtures to evaluate the combined effects of the following factors on workability and rheological properties: water-binder (w/b), sand-binder (s/b), superplasticizer-binder (SP/ b) ratios and maximum aggregate size (Dmax). A mini-slump cone, a Marsh cone and a rotational viscometer was used to evaluate the workability and rheological properties of ECC mixtures. Compressive strength and four point bending tests was used for mechanical characteristics of ECC mixtures at 28 days. The effects of studied parameters (w/b, s/b, SP/b and Dmax) was characterized and analyzed using regression models, which can identify the primary factors and their interactions on the measured properties. Statistically significant regression models was developed for all tested parameters as function of w/b, s/b, SP/b and Dmax. To find out the best possible ECC mixture under the range of parameters investigated for the desired workability and mechanical characteristics, a multi-objective optimization problem was defined and solved based on the developed regression models. Experimental results indicate that w/b, s/b and SP/b parameters affect the rheological and workability properties. On the other hand, for the range of studied aggregate sizes, D_{max} is found to be statistically insignificant on the rheological and workability properties of ECC, also in addition to that the mid-span beam deflection capacities, which reflect material ductility, of ECC mixtures varied noticeably with the change of s/b and D_{max} design parameters. Both of these two parameters negatively affect the deflection capacity of the ECC mixtures. The other parameters have almost no effect on the mid-span beam deflection capacities of ECC mixtures.

Pajak and Ponikiewski (2013) carried out experimental study to investigate the flexural behavior of self-compacting concrete reinforced with straight and hooked end steel fibres at levels of 0.5%, 1.0% and 1.5% and compare it to Normally Vibrated Concrete (NVC). The laboratory tests were determined according to RILEM TC 162-TDF recommendation. The flexural behaviour of SCC appeared to be comparable to NCV, where the increase of fibres volume ratio cause the increase in pre peak and postpeak parameters of SCC. Nevertheless, the type of steel fibres influences much this dependency. However, the SCC achieves the maximum crack mouth displacement for lower deflections than NVC

Qian et al. (2010) carried out experimental study to investigate the self-healing behavior of ECC with focus on the influence of curing condition and precracking time. Four-point bending tests was used to pre crack ECC beams at different age, followed by different curing conditions, including air curing, 3% CO2 concentration curing, cyclic wet/dry (dry under 3% CO2 concentration) curing and water curing. For all curing conditions, deflection capacity after self-healing can recover or even exceed that from virgin samples with almost all precracking ages. After self-healing, flexural stiffness was also retained significantly compared with that from virgin samples, even though the level of retaining decreases with the increase of precracking time. The flexural strength increases for samples pre-cracked at the age of 14 days and 28 days, presumably due to continuous hydration of cementitious materials afterwards. Furthermore, it was promising to utilize nanoclay as distributed internal water reservoirs to promote self healing behaviour within ECC without relying on external water supply.

Satya Prakash (2016) reported in their study about the modulus of elasticity of beam under flexural loading using ANSYS. To determine the modulus of elasticity by nonlinear finite element analysis he used model size of 250x300x4800 mm and with different grades of concrete like M20, M25, M30 and percentage of tension reinforcement varying 0.54 to 1.26% using ANSYS. The Value of 'E' was evaluated for each of the grade of concrete and from the results it was observed that Modulus of Elasticity for RCC is more than the Modulus of Elasticity for PCC and hence deformations are expected to be on lower side. He also observed that the load carrying capacity of the specimens was highly enhanced due to higher grade of concrete and reinforcement.

Sabaa & Ravindrarajah (1999) had mentioned that workability is a very important property of concrete which will affect the rate of placement & the degree of compaction of concrete. Cement Association of Canada (2003) stated that the workability is the ease of placing, combining & finishing freshly concrete mixed and the degree to which it resists segregation. It is also mentioned in IS 7320-1974 that a slump less than 25mm will indicate a very stiff concrete and a slump more than 125mm will indicate a very runny concrete.

Salahuddin Qudah, Mohamed Malej (2014) experimentally studied the failure of beam–column connections due to multiple load cycles may lead to collapse of the whole structure. The ECC can be used to enhance the response of beam–column connections subjected to reverse cyclic loadings. The main objective of this research is to investigate the structural behavior of beam–column connections incorporating an ultra-ductile ECC replacement of concrete and transverse reinforcement within the plastic zone in both column and beams as well as the joint core of the beam–column connection. To demonstrate that ECC can be used instead of RC to improve shear strength, energy absorption capacity and ductility, thus, reducing reinforcement congestion and construction complexity. A laboratory investigation was conducted to study the behavior and response of a interior beam–column connection that is part of a building. The investigation included 9 specimens, each representing one-third scale interior beam–column connection. Each specimen consisted of a portion of horizontal beam and part of upper and lower column which form the connection.

The test results in the study revealed that the use of ECC has imparted to the specimens a greater ability to resist and survive the reverse-cyclic loading steps. It was also found that the ultimate load of specimens incorporating ECC was greatly enhanced.

S.M. Gadhiya (2013) has carried out parametric study on bendable concrete to find out compressive strength, flexural strength and deflection characteristic for different types of fibres for varying depth of beams. Comparison study for fresh and hardened properties of concrete has been carried out for different fibers and deflection of specimen with respect to the depth of specimen found out. The results shows that the compressive strength of ECC with steel fibres is 5% more than Conventional concrete were as for PVA and Hybrid fibres it is 15% and 20% less than Conventional Concrete. Density of ECC is 20% lower than conventional concrete. Flexural Strength and deflection is inversely related with the cross section of the specimen. ECC with increasing % fibres increases 20% of Energy Absorption whereas by increasing cross section of the specimen, 10% of increment in Energy absorption is evaluated.

Srinivasa. C. H. et al. reported various experiments reviews that there is a lot of innovative research were taking place around the world in studying and developing the various parameters of ECC. The mix proportioning of ECC was mainly based on micro mechanical modelling of constituents of ECC. The different researchers had proposed different mix proportions based on the various rheological parameters of ECC and this paper illustrates important facts of various research activities that are going around the world on studying various rheological and hardened properties of Engineered Cementitious Composites (ECC). Engineered Cementitious Composites design is mainly based on micromechanical modelling with strain capacity exceeding 3 to 5% compared to that 0.01% of normal concrete and volume fraction of the fibre is also less than 2% compared large amount of fibres say 5-10% in FRCC.

Shuxin wang and Victor c. Li reported that Engineered cementitious composites (ECCs) are representing the latest generation of fiber-reinforced cementitious composites (FRCC) with noticeable improvement in strain-hardening behaviour. As ECCs possess high tensile and durability properties, due to the high usage cement in the mixture resulted vast environmental and economical impacts. In this mentioned paper, the study of mechanical properties of ECCs by incorporating the high volume bottom ash and fly ash is reported. Importance is focussed on the influence of fly ash content which promotes the key micromechanical properties relevant to composite ductility. It is revealed that a high volume faction of fly ash tends to reduce the polyvinyl alcohol fiber and matrix interface and matrix toughness is in the favour of attaining high tensile strain capacity. The cement substituted with bottom ash and fly ash is subjected to a constrained parameter i.e. compressive strength. The micromechanical interaction parameter study revealed the general descending trend of interface frictional stress and chemical bond with increase of fly ash content, which in turn modifies the PVA fiber matrix bridging. In addition, an increase of fly ash content also leads to lowering of the matrix toughness both trends are favourable for strain hardening. Strong correlation between the matrix and fiber strain capacity was observed, which is a good indication of composite strain hardening potential. It is mentioned that a proper mixture proportioning process can achieve high material performance even when using locally available low quality waste products as cement substitutions, as long as the governing micromechanics parameters were carefully checked. Although the study is mainly focused on flexural ductility of cementitious composites, the researchers believe that this approach is broadly applicable to other sustainable material design practice.

Soutsos et al. (2012) carried out experimental study on commercially available steel and synthetic fibres. Flexural stress – deflection relationships have been used to determine: flexural strength, flexural toughness, equivalent flexural strength, and equivalent flexural strength ratio. The flexural toughness of concrete was found to increase considerably when steel and synthetic fibres were used. However, equal dosages of different fibres did not result in specimens with the same flexural toughness.

Tahir Kemal Erdem (2014) carried out experimental work to study size effect on the residual properties of ECC was investigated on the specimens exposed to high temperatures up to 800°C. Cylindrical specimens having different sizes were produced with a standard ECC mixture. Changes in pore structure, residual compressive strength and stress–strain curves due to high temperatures were determined after air cooling. Standard ECC mixture (M45) with a fly ash-cement ratio (FA/C) of 1.2 by mass was used in this investigation which was prepared in a standard mortar mixer at water to cementitious material ratio of 0.27. Experimental results indicate that despite the increase of specimen size, no explosive spalling occurred in any of the specimens during the high temperature exposure. Increasing the specimen size and exposure temperature decreased the compressive strength and stiffness. Percent reduction in compressive strength and stiffness due to high temperature was similar for all specimen sizes.

Victor C Li et al. (2012) carried out experimental study to improve the fibre distribution by adjusting the mixing sequence. With the standard mixing sequence, fibres are added after all solid and liquid materials are mixed. The undesirable plastic viscosity before the fibre addition may cause poor fibre distribution and results in poor hardened properties. With the adjusted mixing sequence, the mix of solid materials with the liquid material is divided into two steps and the addition of fibres is between the two steps. In this paper, the influence of different water mixing sequences was investigated by comparing the experimental results of the uniaxial tensile test and the fibre distribution analysis. The result was concluded that compared with the standard mixing sequence, the adjusted mixing sequence increases the tensile strain capacity and ultimate tensile strength of ECC and improves the fibre distribution.

Yu Zhu et al. (2012) carried out an experimental study to develop a kind of green ECC with high tensile ductility and strong enough matrix strength, especially at early age. A series of investigations was carried out to evaluate mechanical properties and drying shrinkage of ECC with 70% combination mineral admixtures of FA and ground granulated blast furnace slag (SL). Four ECC mixtures with constant W/B of 0.25 are prepared with combined inclusion of FA and SL as constant cement replacement level of 70%. The laboratory measurements are carried out, including direct tensile test, fourpoint bending test, and compressive strength and drying shrinkage. The experimental results show that ECC with combination mineral admixtures can achieve strain hardening behavior, tensile capacity of ECC can be more than 2.5% at 90 days. Meanwhile, compared to ECC only with fly ash, slag and fly ash can effectively increase compressive strength of ECC, especially at early age. Incorporating SL into matrix can slightly increase drying shrinkage of ECC. However, among four ECC mixtures, ECC with 30% SL and 40% FA presents the lowest drying shrinkage at later ages.

Yu Zhu et al. (2014) carried out experimental study to investigate the mechanical properties of ECC produced by high volume mineral admixtures which are fly ash, slag and silica fume. Emphasis of this study is placed on building the correlation between compressive strength and the parameters obtained in load–deflection curves of 12 different ECC mixtures in binary and ternary system of binder materials with different mineral admixtures (FA, SL and silica fume) and to build the correlation between compressive strength and durability of ECC. The water-binder materials ratio (W/B) is kept at 0.25 for various ECC mixtures. The replacement levels of different mineral admixtures in all ECCs in binary systems of binder materials are 50%, 60%, 70% and 80%, respectively (FA + cement and SL + cement). In ternary system (FA + SL + cement and FA + SF + cement), the total replacement of mineral admixtures is 70%, the ratios of FA/SL and FA/SF are different in ECC mixture proportions. The toughness behaviour and compressive strength of 12 different ECC mixtures are firstly measured by four point bending test and compressive strength test, respectively. The results indicate that the compressive strength has an inverse relationship with deflection, toughness index and fracture energy, respectively; but the compressive strength have a direct proportional relation with flexural strength, first cracking load, and peaking load, respectively. Additionally, in the binary system of binder materials, the ductility of ECC can be obviously improved by introducing high volume fly ash and slag replacing the cement, respectively. However, the compressive strength of ECC with fly ash and slag can reduce 40% and 14%, respectively. For the ternary system of binder materials with replacement 70% of cement, the combination of fly ash and slag can keep not only the excellent ductility of ECC, but also enough stronger matrix strength. Meanwhile, the combination of fly ash and silica fume only increase the compressive strength, but weaken the toughness of ECC.

Yi Shao, Sarah L. Billington (2019) experimentally studied Flexural performance of steel-reinforced engineered cementitious composites with different reinforcing ratios and steel types and found Reinforced engineered cementitious composites (ECC) flexural members fail either after a dominant crack forms or after gradual strain hardening of reinforcing steel. These two failure paths represent distinct ductility ranges and load reduction mechanisms that have not been fully characterized.

Their study experimentally investigates the two failure paths of flexural members with different reinforcing ratios (0.53%–2.10%), two types of reinforcing steel (A615 Grade 60 and A1035 Grade 100), and under monotonic and cyclic loading conditions.

Their Study Results show that the two failure paths are affected by the reinforcing ratio and steel type, ECC sustains a maximum compressive strain that is larger than 1.0% before crushing, ECC effectively restrains crack width opening for flexural members using high strength (Grade 100) steel reinforcement, A maximum compressive strain of at least 1.2%–3.0% is sustained by ECC before crushing in all of the reinforced ECC beams that were tested in the study.

CHAPTER-4 LITERATURE SUMMARY

- Compared with the standard mixing sequence, by adjusting mixing sequence increases the tensile strain capacity and ultimate tensile strength of ECC and improves the fibre distribution.
- Increasing the specimen size and exposure temperature decreased the compressive strength and stiffness.
- The compressive strength of ECC with steel fibres is 5% more than Conventional concrete were as for PVA and Hybrid fibres it is 15% and 20% less than Conventional concrete.
- ECC with increasing percentage of Fibres increases about 20% of Energy Absorption.
- High volume fly-ash ECC maintained its unique characteristics of multiple-cracking, strain hardening and tight crack width control in extreme temperature condition.
- ECC enhanced specimen exhibits a higher capacity compared to the conventional concrete.
- Ultimate tensile strength and tensile strain capacity of ECC is higher than conventional concrete without cracks.
- Addition of fibres did not noticeably change the compressive strength, indirect tensile strength or modulus of elasticity of SCC for any of the amounts, types or combination of fibres used.
- As the compressive strength and the volume of fraction fibres increase, the shear strength also increases.

CHAPTER-5 RESEARCH GAP

In the world of materials engineering, raw ingredients are shaped into a composite material through processing. Traditionally, raw ingredient selection is based on empiricism. In recent years, composite materials are systematically being designed. One such material is "Engineered Cementitious Composite (ECC)."

Engineered Cementitious Composite commonly known as ECC, developed in the last decade may prove a safer, more durable, and sustainable concrete material which is environmental friendly, cost-effective and constructed with conventional construction equipment.

ECC is ductile in nature. Under flexure, normal concrete fractures in a brittle manner.

In contrast, very high curvature can be achieved for ECC at increasingly higher loads, much like a ductile metal yielding. Structural designers have found the damage tolerance and inherent tight crack width control of ECC. It has wide applications and scope in various fields of Civil Engineering.

In the previous research works it has not been clarified the behaviour of concrete beam with a layer of ECC in the tension zone so that we may find out the properties of beams as ECC being flexible in nature.

In my research work I will analyse the beams of different grades with a layer of ECC in the concrete beams and will found out the behaviour of the beam under different loads. ECC being flexible in nature will help us to find out the criteria under which it can be used for different purposes such as retrofitting of the structures, as concrete is a brittle in nature cracking, damage and deterioration occurs and it requires repeated maintenance of the structure members.

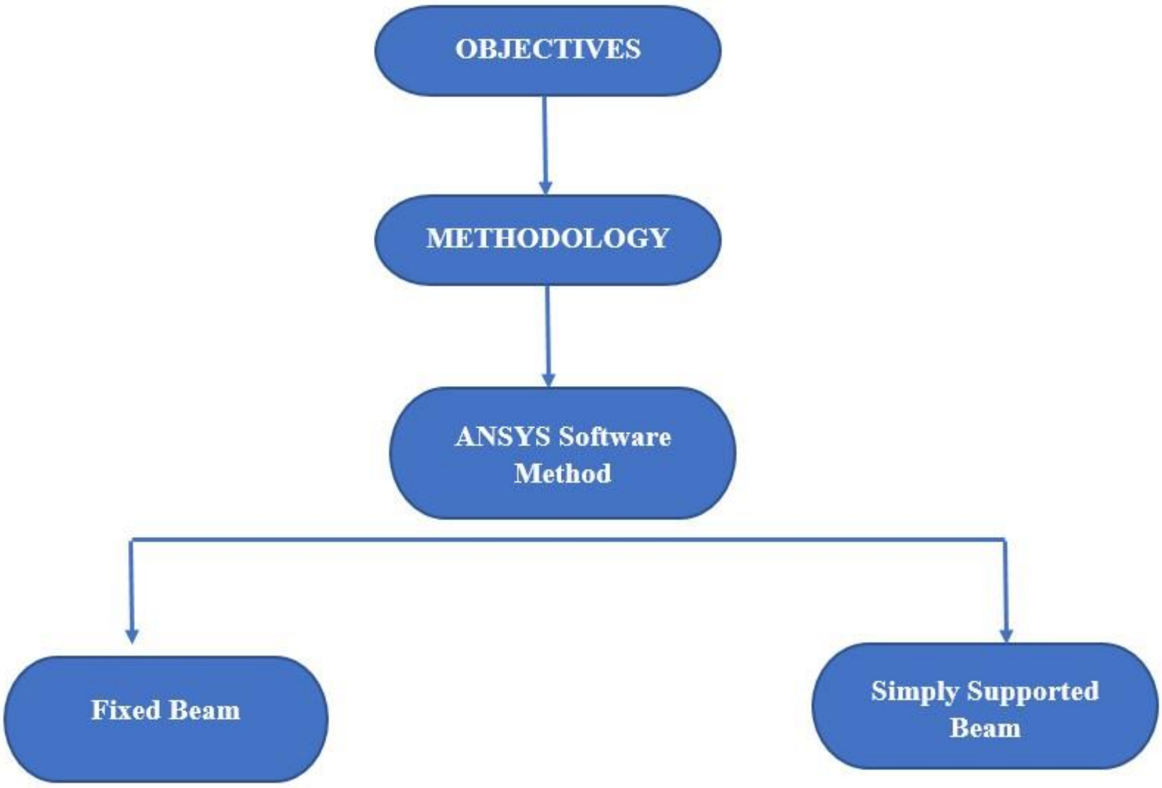
Therefore the goals of this study are to study the behaviour of the ECC beams under different loading impact loading and temperature conditions, to analyse the beams using ANSYS software.

We looked into that the conventional concrete will be subjected to a greater pressure before it breaks. A new type of flexible concrete that bends under such pressure and can repair itself. The self-healing concrete develops many hairline fractures when bent, distributing the pressure over its area. The tiny cracks will seal themselves with calcium carbonate when exposed to rainwater and carbon dioxide. This new flexible concrete as Bendable Concrete or ECC.

“The flexible concrete (ECC) bends but doesn’t break.” This was reported by Victor Li and Benjamin Wylie. This means that the before complete failure ECC will show some cracks and being self-healing in nature it can self-heal themselves.

CHAPTER-6 METHODOLOGY

Using *ANSYS* software:



6.1 USING *ANSYS* SOFTWARE:

Ansys software will be used to analyse the beams by using the theoretical values obtained from the laboratory experiments.

6.1.1 MODELING IN ANSYS

In ANSYS modelling and analysis can be done in two ways either with MECHANICAL APDL or with ANSYS WORK BENCH. In comparison of both these tools APDL is not user-friendly, which includes lot of detailing and is time consuming. Error identification is bit difficult in APDL but in the case of WORKBENCH it is a lot easier. Modelling in work bench is the quite advanced and all the tools are predefined having easy user interface. In comparison of these two tools WORKBENCH is preferable because the geometry required for this research is quite complicated to model and involves minute detailing. One should incorporate the fillet edged stirrups in the concrete block which is the very difficult in APDL. Further analyses are done in the division of mechanical. All the material properties are available (predefined) in the engineering data table but even though manually the properties are assigned because some of the predefined properties are not acceptable in this design analysis. The material properties for concrete are taken as per standards.

6.1.2 MESHING IN ANSYS

Meshing plays a vital role in FEM. Meshing is nothing but dividing a specific object or element in to number of smaller parts for analysis. As per basically in ANSYS meshing can be done in two ways i.e., either automatically nothing but predefined which is default or user defined. In automatic meshing software operates the meshing in which the size of the element, relevance factor, curvature and proximity etc., are default. In case of user defined meshing, user can define all the parameters according to the required output and the method of meshing can also be assigned based on the requirement.

6.2 Data Used

6.2.1 Beam Design Data:

For Simply Supported Beams:

	Beam Design Data								
Specimen No.	**Material**	**Dimensions (mm)**	**ECC Layer (mm)**	**Grade of Concrete**	**Concrete**		**ECC**		**Load (kN/m)**
		l*b*d			E(GPA)	Poisson Ratio	E(GPA)	Poisson Ratio	
Concrete beam	Concrete	2000*250*300	0	M35	29.58	0.21	-	-	50
ECC 1 (A)	ECC 1	2000*250*300	25	M35	29.58	0.21	18.8	0.14	50
ECC 1 (B)	ECC 1	2000*250*300	30	M35	29.58	0.21	18.8	0.14	50
ECC 1 (C)	ECC 1	2000*250*300	45	M35	29.58	0.21	18.8	0.14	50
ECC 1 (D)	ECC 1	2000*250*300	50	M35	29.58	0.21	18.8	0.14	50
	Material	**Dimensions (mm)**	**ECC Layer (mm)**	**Grade of Concrete**	**Concrete**		**ECC**		
		l*b*d			E(GPA)	Poisson Ratio	E(GPA)	Poisson Ratio	
ECC 2 (A)	ECC 2	2000*250*300	25	M35	29.58	0.21	19	0.16	50
ECC 2 (B)	ECC 2	2000*250*300	30	M35	29.58	0.21	19	0.16	50
ECC 2 (C)	ECC 2	2000*250*300	45	M35	29.58	0.21	19	0.16	50
ECC 2 (D)	ECC 2	2000*250*300	50	M35	29.58	0.21	19	0.16	50
	Material	**Dimensions (mm)**	**ECC Layer (mm)**	**Grade of Concrete**	**Concrete**		**ECC**		
		l*b*d			E(GPA)	Poisson Ratio	E(GPA)	Poisson Ratio	
ECC 3 (A)	ECC 3	2000*250*300	25	M35	29.58	0.21	19.9	0.18	50
ECC 3 (B)	ECC 3	2000*250*300	30	M35	29.58	0.21	19.9	0.18	50
ECC 3 (C)	ECC 3	2000*250*300	45	M35	29.58	0.21	19.9	0.18	50
ECC 3 (D)	ECC 3	2000*250*300	50	M35	29.58	0.21	19.9	0.18	50

For Fixed Beams:

	Beam Design Data								
Specimen No.	**Material**	**Dimensions (mm)**	**ECC Layer (mm)**	**Grade of Concrete**	**Concrete**		**ECC**		**Load (kN)**
		l*b*d			E(GPA)	Poisson Ratio	E(GPA)	Poisson Ratio	
Concrete beam	Concrete	2000*250*300	0	M35	29.58	0.21	-	-	50
ECC 1 (A)	ECC 1	2000*250*300	25	M35	29.58	0.21	18.8	0.14	50
ECC 1 (B)	ECC 1	2000*250*300	30	M35	29.58	0.21	18.8	0.14	50
ECC 1 (C)	ECC 1	2000*250*300	45	M35	29.58	0.21	18.8	0.14	50
ECC 1 (D)	ECC 1	2000*250*300	50	M35	29.58	0.21	18.8	0.14	50
	Material	**Dimensions (mm)**	**ECC Layer (mm)**	**Grade of Concrete**	**Concrete**		**ECC**		
		l*b*d			E(GPA)	Poisson Ratio	E(GPA)	Poisson Ratio	
ECC 2 (A)	ECC 2	2000*250*300	25	M35	29.58	0.21	19	0.16	50
ECC 2 (B)	ECC 2	2000*250*300	30	M35	29.58	0.21	19	0.16	50
ECC 2 (C)	ECC 2	2000*250*300	45	M35	29.58	0.21	19	0.16	50
ECC 2 (D)	ECC 2	2000*250*300	50	M35	29.58	0.21	19	0.16	50
	Material	**Dimensions (mm)**	**ECC Layer (mm)**	**Grade of Concrete**	**Concrete**		**ECC**		
		l*b*d			E(GPA)	Poisson Ratio	E(GPA)	Poisson Ratio	
ECC 3 (A)	ECC 3	2000*250*300	25	M35	29.58	0.21	19.9	0.18	50
ECC 3 (B)	ECC 3	2000*250*300	30	M35	29.58	0.21	19.9	0.18	50
ECC 3 (C)	ECC 3	2000*250*300	45	M35	29.58	0.21	19.9	0.18	50
ECC 3 (D)	ECC 3	2000*250*300	50	M35	29.58	0.21	19.9	0.18	50

- Above used data has been used for the analysis of ECC composite beams
- The data of ECC Material has been used from lietratures.
- The Grade of concrete used is M35.

6.3 Properties of Material

The ECC materials have been named as ECC 1 , ECC 2 and ECC 3 the details are as:

Specimen Mixture:

Mixture	**Cement**	**Fly Ash**	**Silica sand**	**w/cm**	**HRWRA**	**PVA (%V_f)**	**SMA (%V_f)**
ECC 1	1	1.2	0.8	0.26	0.012	2	0.5
ECC 2	1	1.2	0.8	0.26	0.012	2.5	1.0
ECC 3	1	1.2	0.8	0.26	0.012	2.8	1.5

Cement

Cement, in general, adhesive substances of all kinds, but, in a narrower sense, the binding materials used in building and civil engineering construction. Cements of this kind are finely ground powders that, when mixed with water, set to a hard mass. Setting and hardening result from hydration, which is a chemical combination of the cement compounds with water that yields sub microscopic crystals or a gel-like material with a high surface area. Because of their hydrating properties, constructional cements, which will even set and harden under water, are often called hydraulic cements. The most important of these is Portland cement.

Fly Ash

Fly ash is a fine powder that is a by-product of burning pulverized coal in electric generation power plants. Fly ash is a pozzolan, a substance containing aluminous and siliceous material that forms cement in the presence of water. When mixed with lime and water, fly ash forms a compound similar to Portland cement. This makes fly ash suitable as a prime material in blended cement, mosaic tiles, and hollow blocks, among other building materials. When used in concrete mixes, fly ash improves the strength and segregation of the concrete and makes it easier to pump.

Silica Sand

Silica sand, also known as quartz sand, white sand, or industrial sand, is made up of two main elements: silica and oxygen. Specifically, silica sand is made up of silicon dioxide ($SiO2$).

HRWRA

High Range Water Reducers also known as, Superplasticizers (SP's), are additives used in making high strength concrete. Plasticizers are chemical compounds that enable the production of concrete with approximately 15% less water content. Superplasticizers allow reduction in water content by 30% or more. These additives are employed at the level of a few weight percent. Plasticizers and superplasticizers retard the curing of concrete.

PVA

Polyvinyl alcohol (PVA) fiber, a newly developed high performance fiber, is used in ECC to help achieve high tensile strain capacity, toughness and structural integrity that is vital to pavement overlays. The design of the modified ECC to be studied in this research included PVA fibers; however, other mix components and proportions were altered to more closely follow standard concrete pavement design. This was done in hope of gaining the benefits of PVA-ECC, including tensile ductility and high flexural strength, while still maintaining important performance characteristics of conventional concrete pavement.

SMA

A shape-memory alloy is an alloy that can be deformed when cold but returns to its pre-deformed ("remembered") shape when heated. It may also be called memory metal, memory alloy, smart metal, smart alloy, or muscle wire.

Parts made of shape-memory alloys can be lightweight, solid-state alternatives to conventional actuators such as hydraulic, pneumatic, and motor-based systems. They can also be used to make hermetic joints in metal tubing.

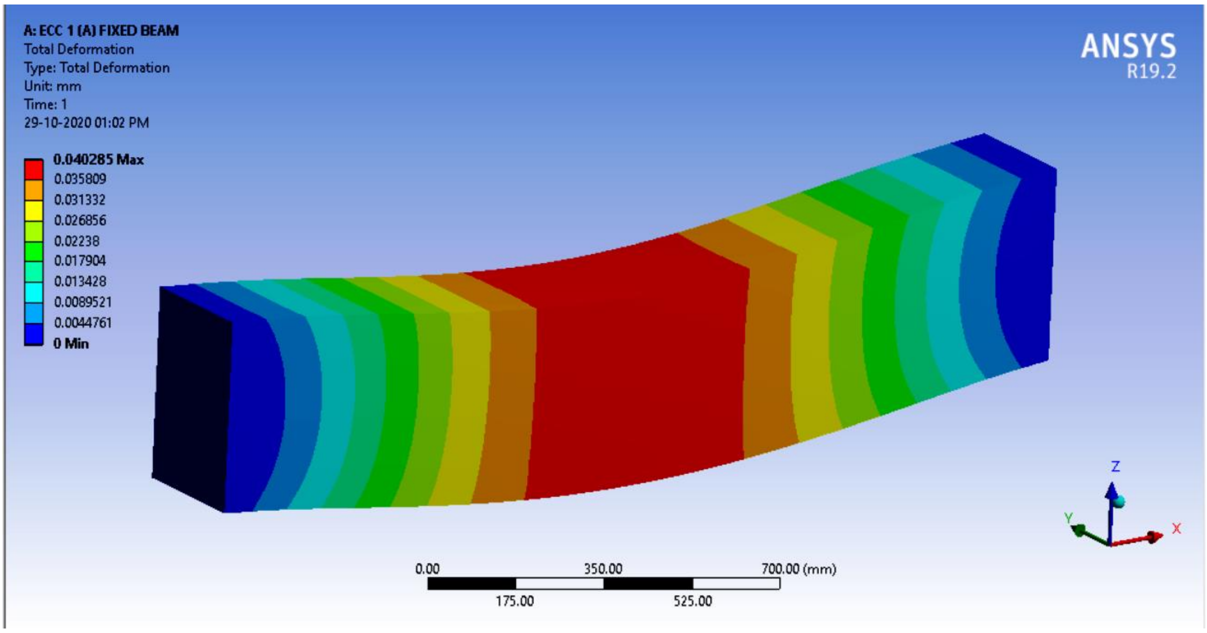
CHAPTER-7 ANALYSIS

7.1 Deflection Analysis of ECC composites using ANSYS

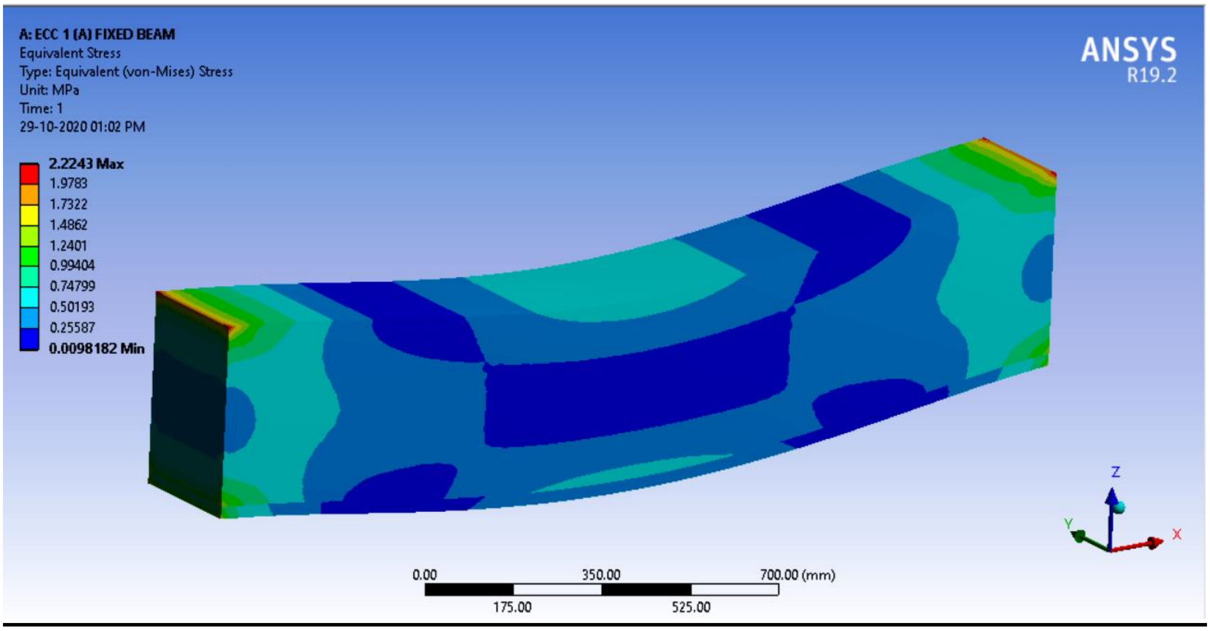
Deflection and Stress for Fixed Beams

ECC 1 (A)

Deflection

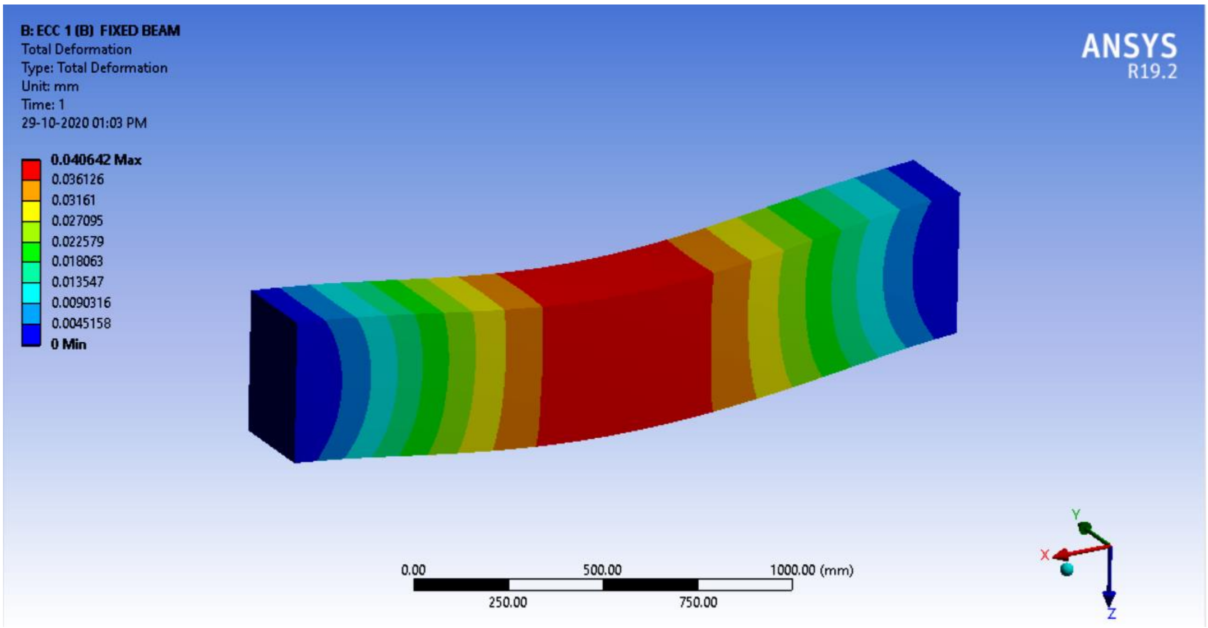


Stress



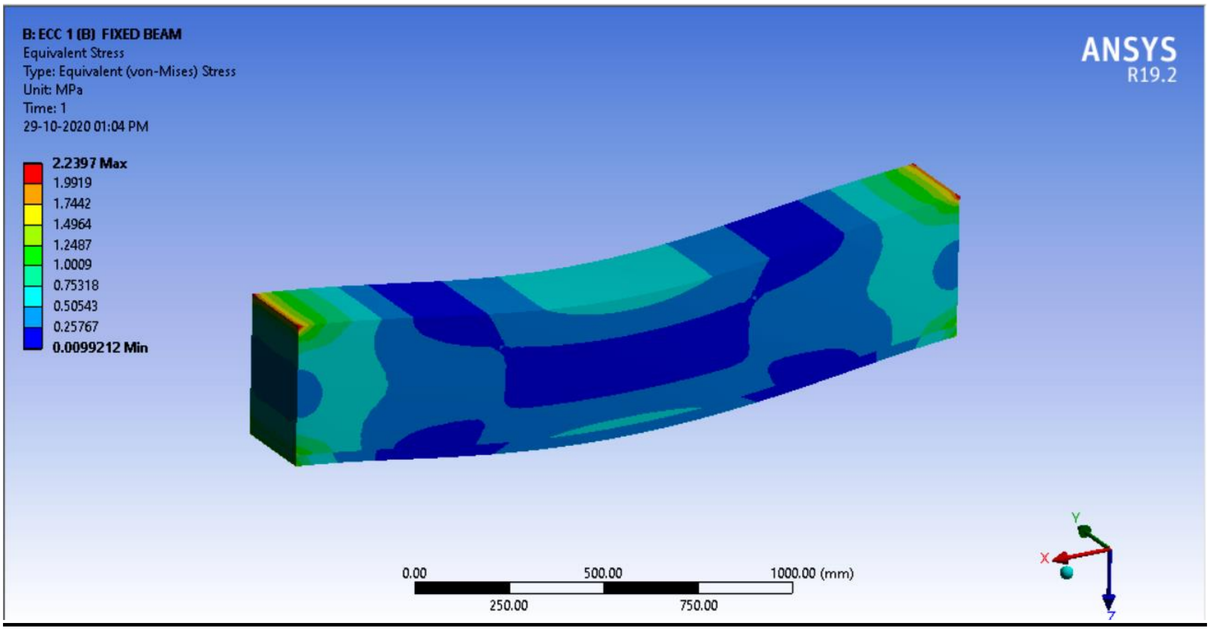
ECC 1 (B)

Deflection



B: ECC 1 (B) FIXED BEAM
Total Deformation
Type: Total Deformation
Unit: mm
Time: 1
29-10-2020 01:03 PM

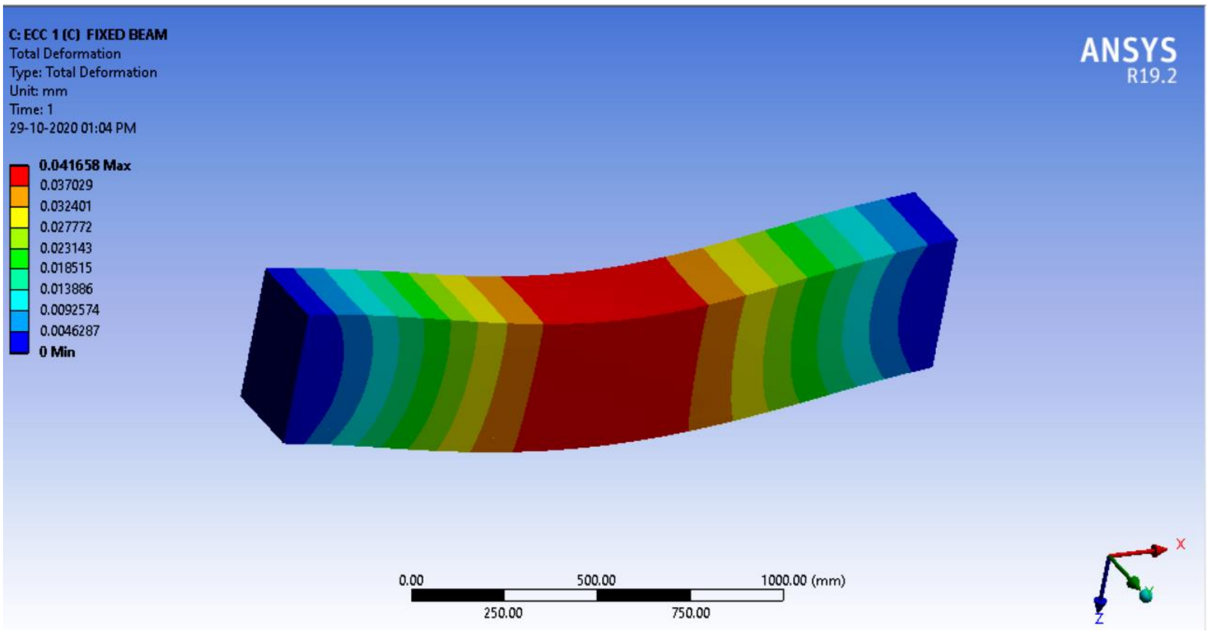
Stress



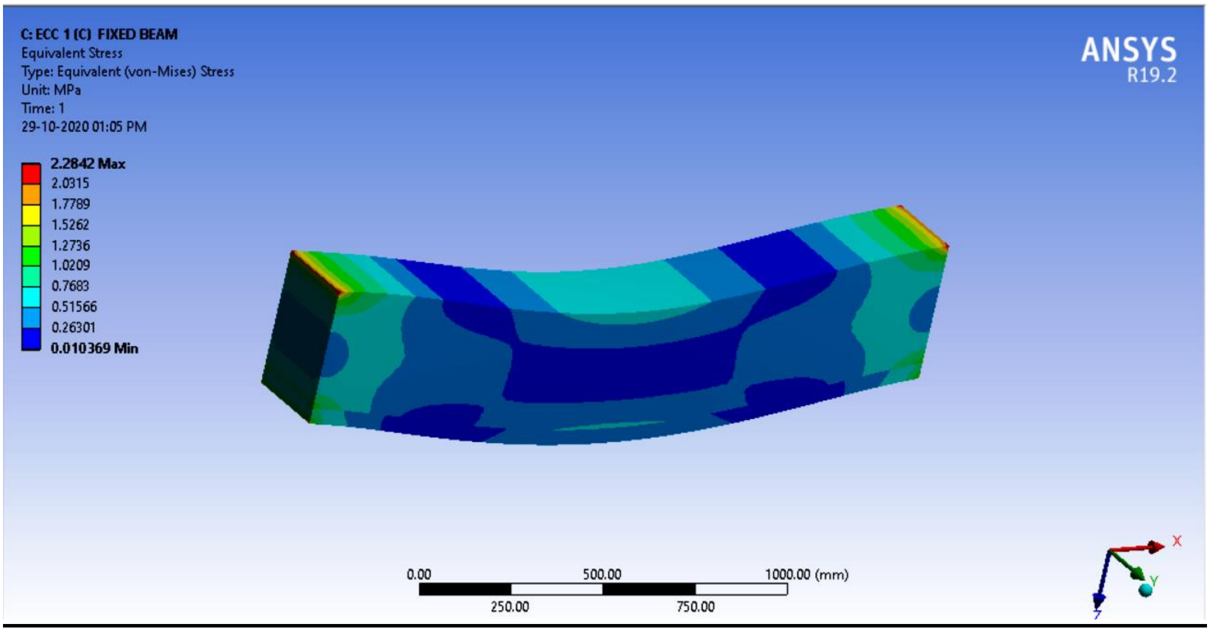
B: ECC 1 (B) FIXED BEAM
Equivalent Stress
Type: Equivalent (von-Mises) Stress
Unit: MPa
Time: 1
29-10-2020 01:04 PM

ECC 1 (C)

Deflection

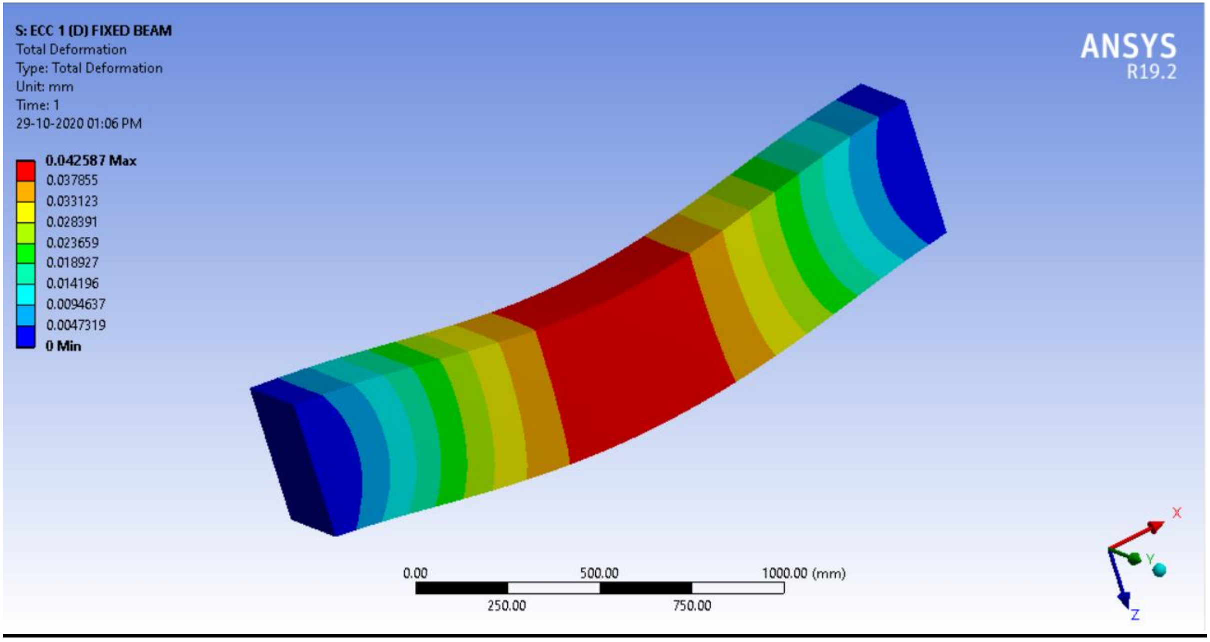


Stress

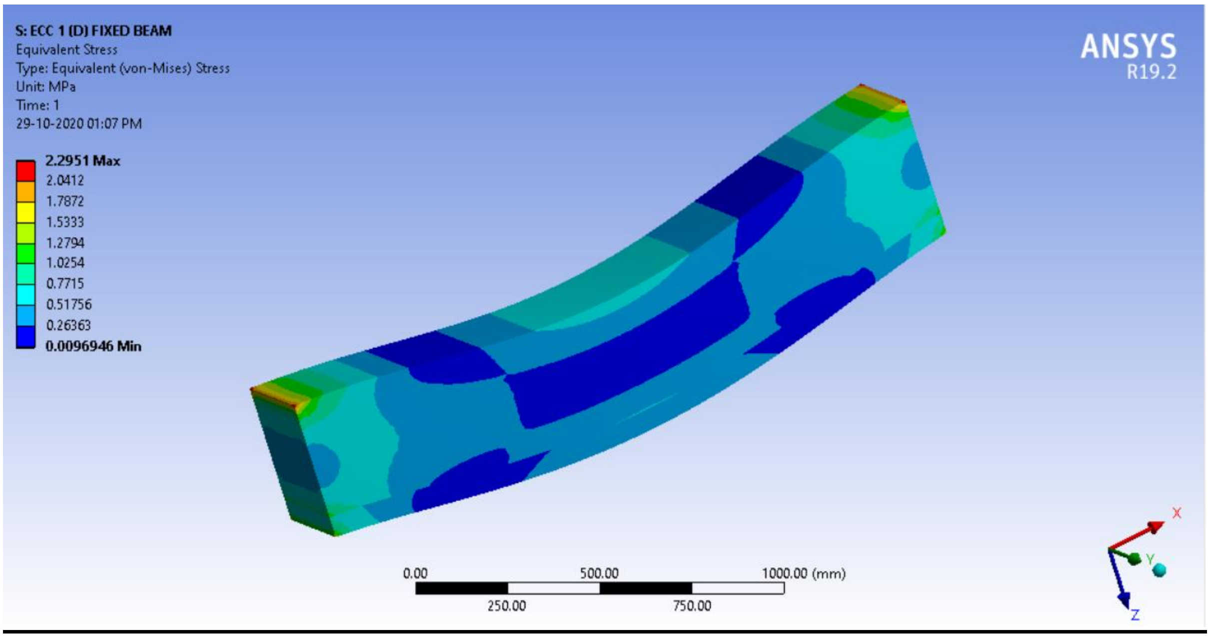


ECC 1 (D)

Deflection

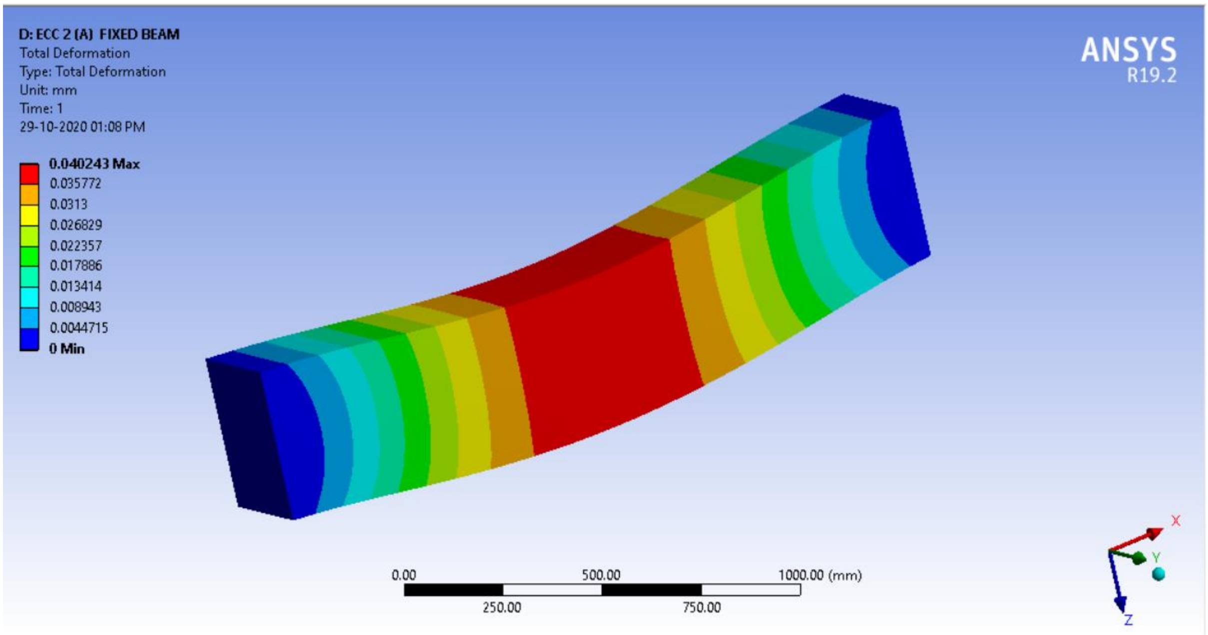


Stress

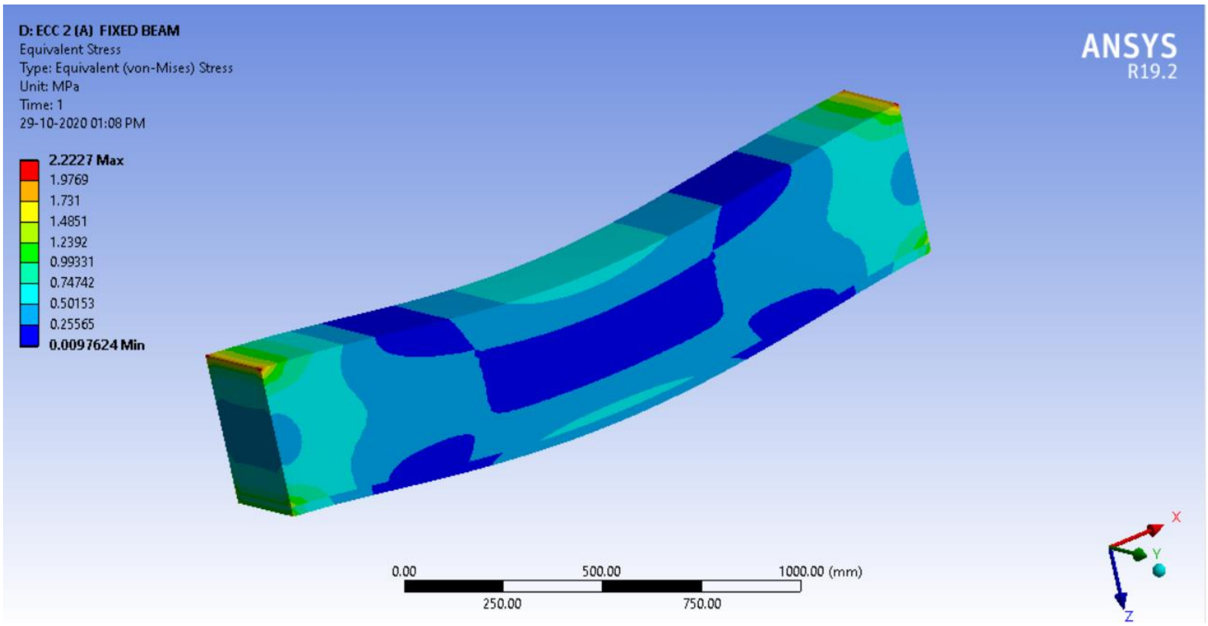


ECC 2 (A)

Deflection

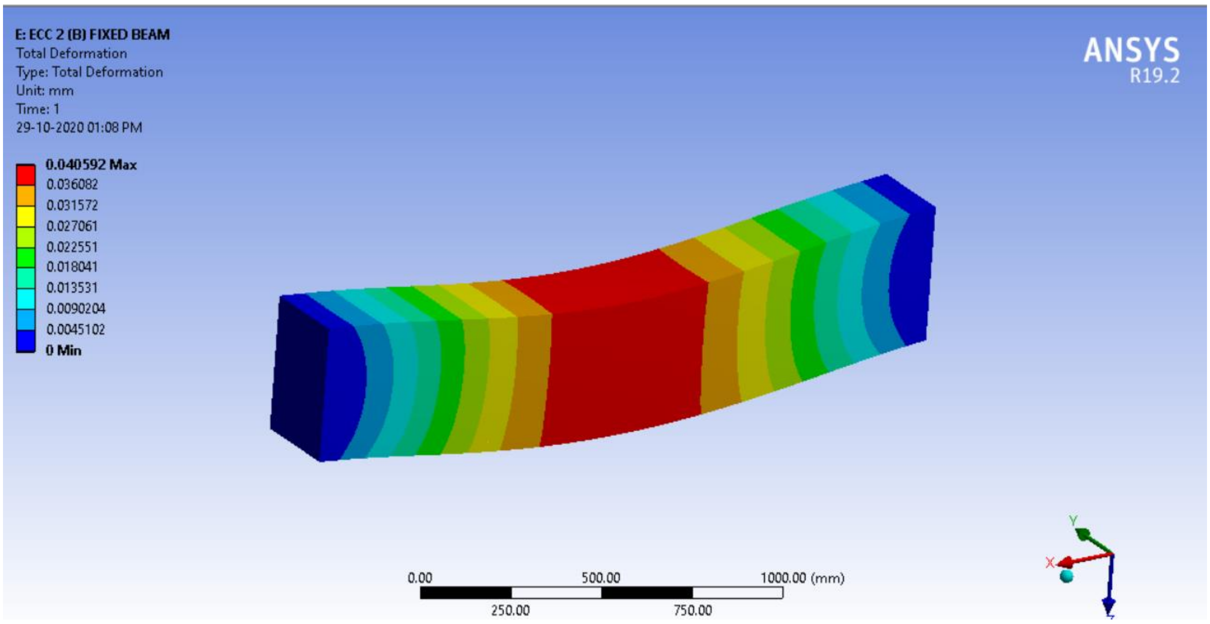


Stress

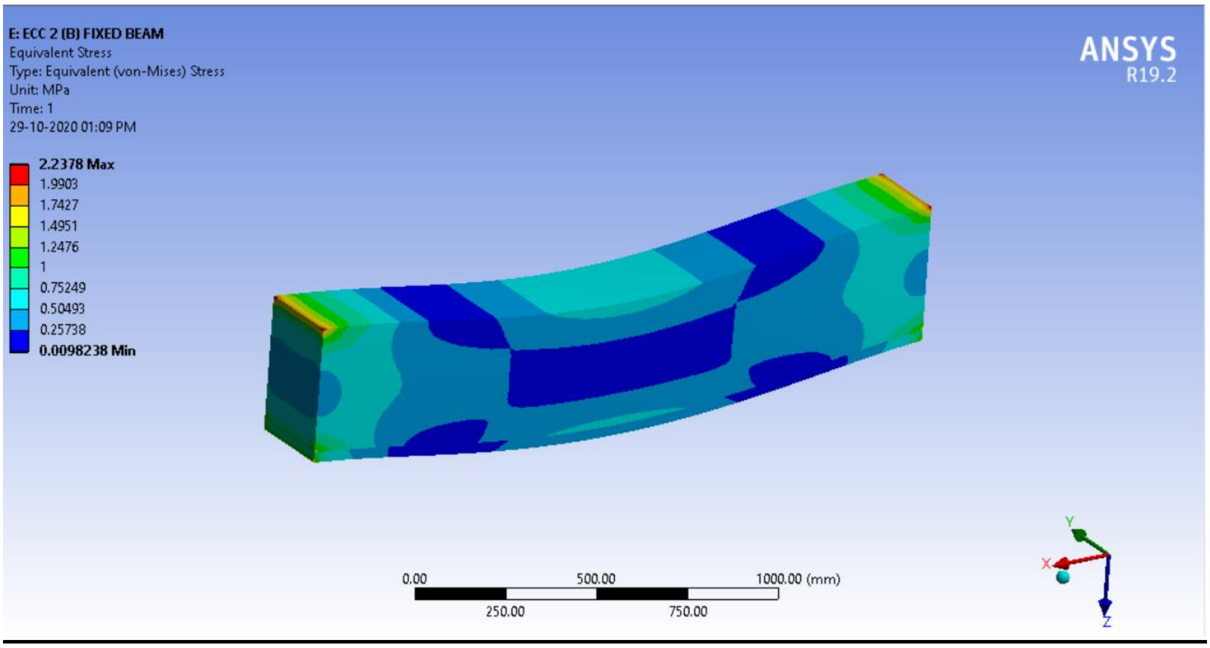


ECC 2 (B)

Deflection

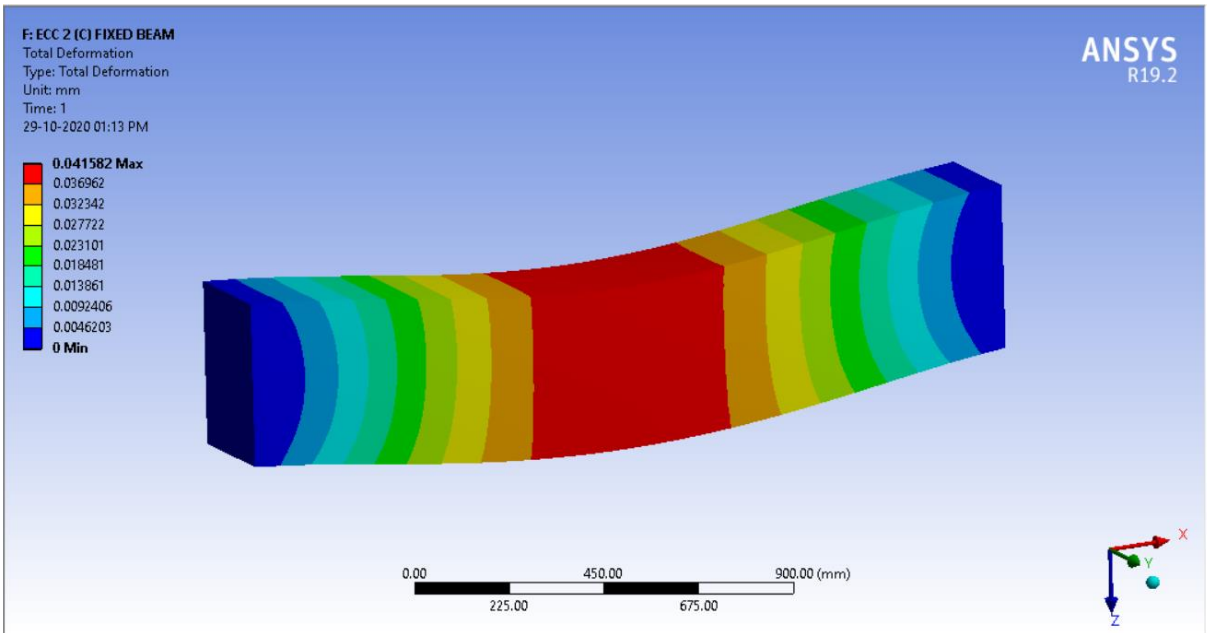


Stress

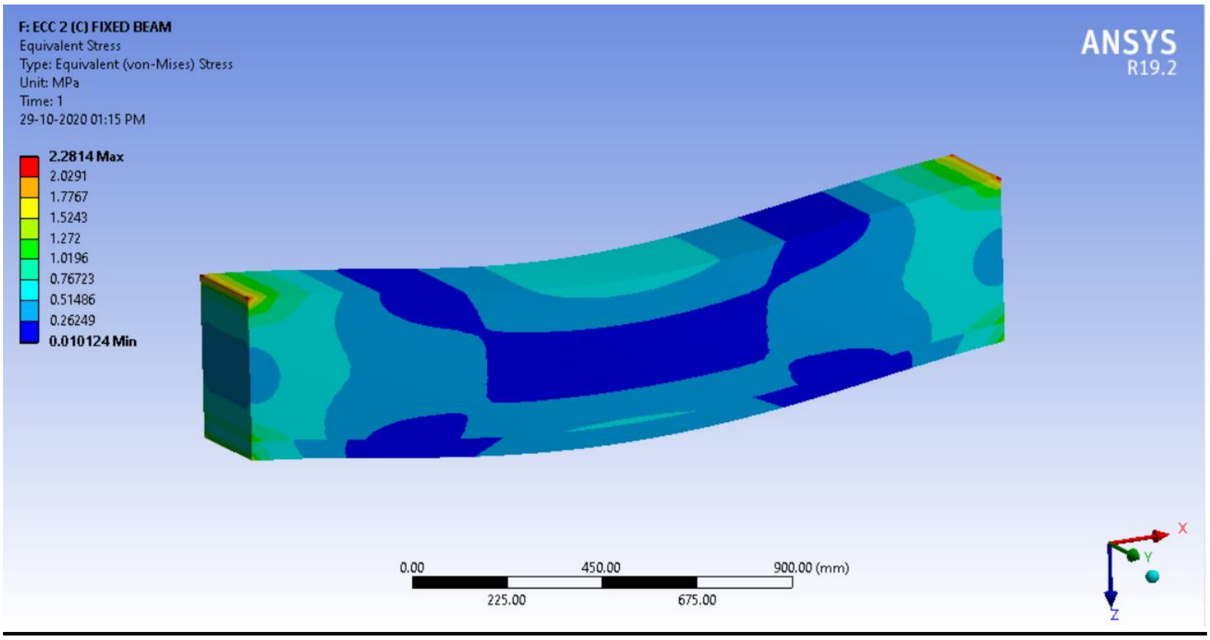


ECC 2 (C)

Deflection

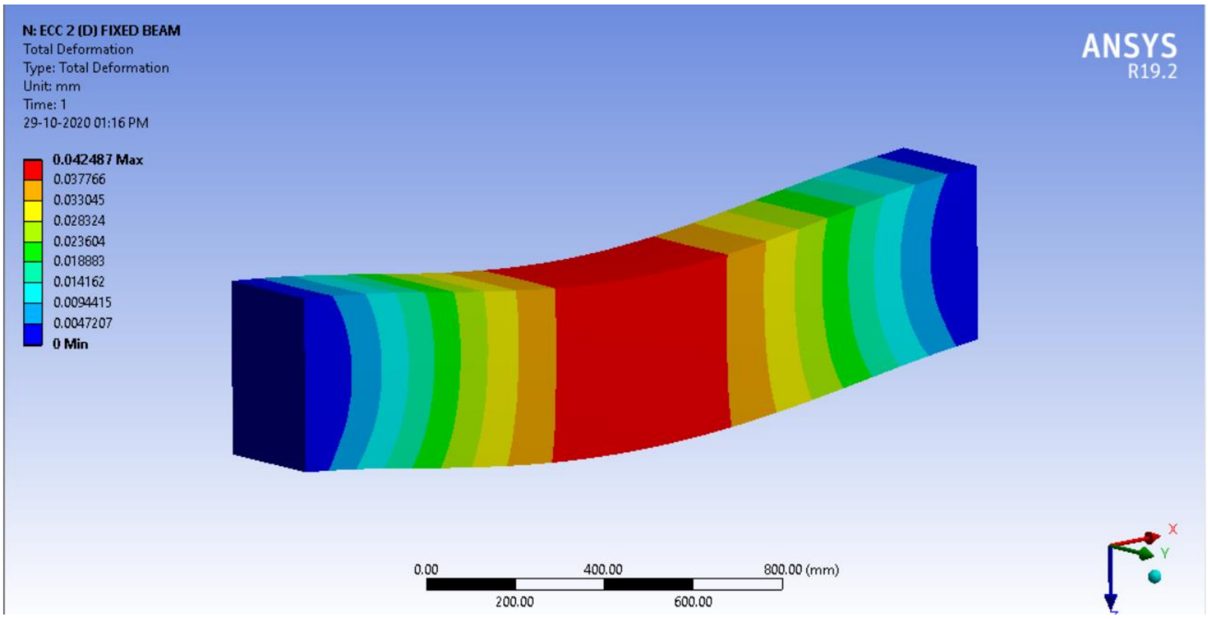


Stress

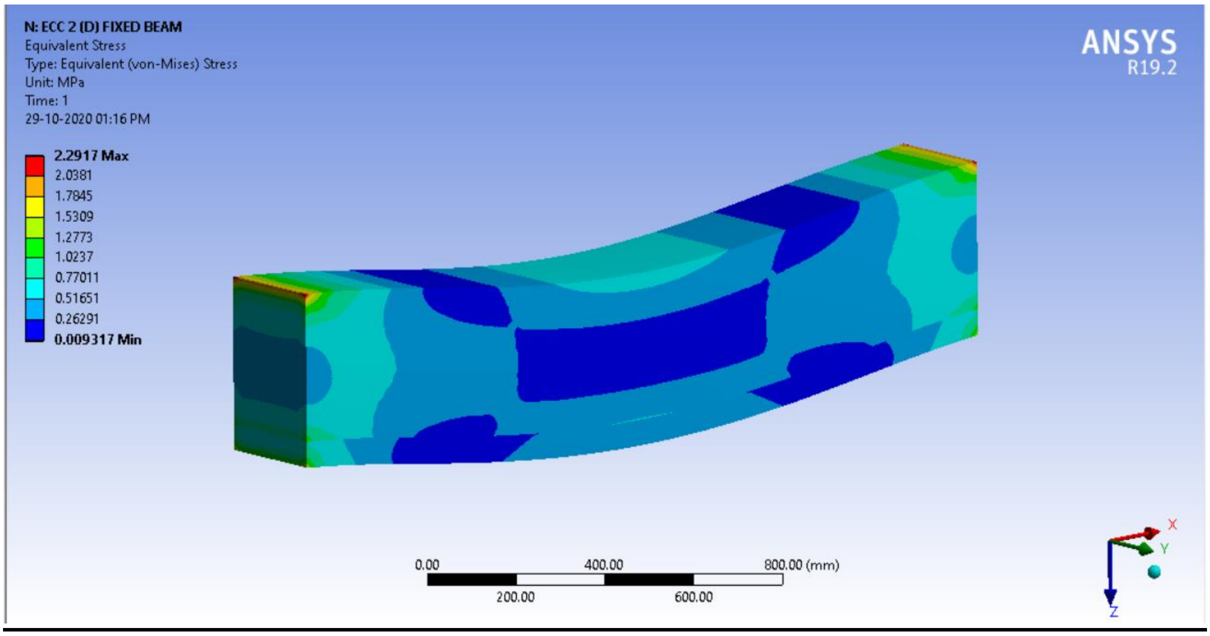


ECC 2 (D)

Deflection

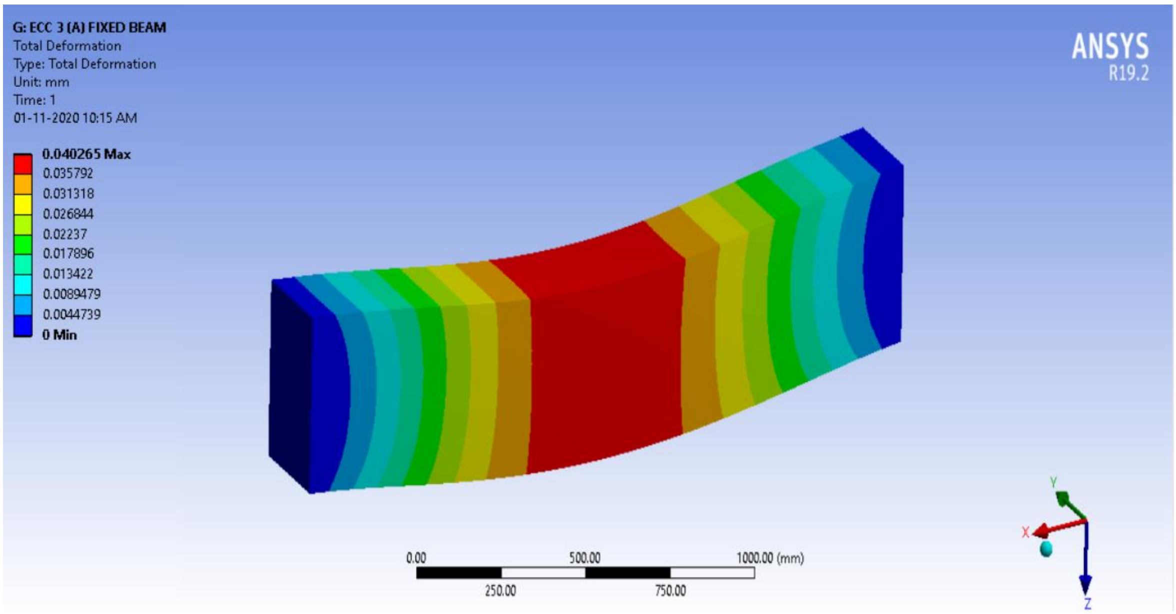


Stress

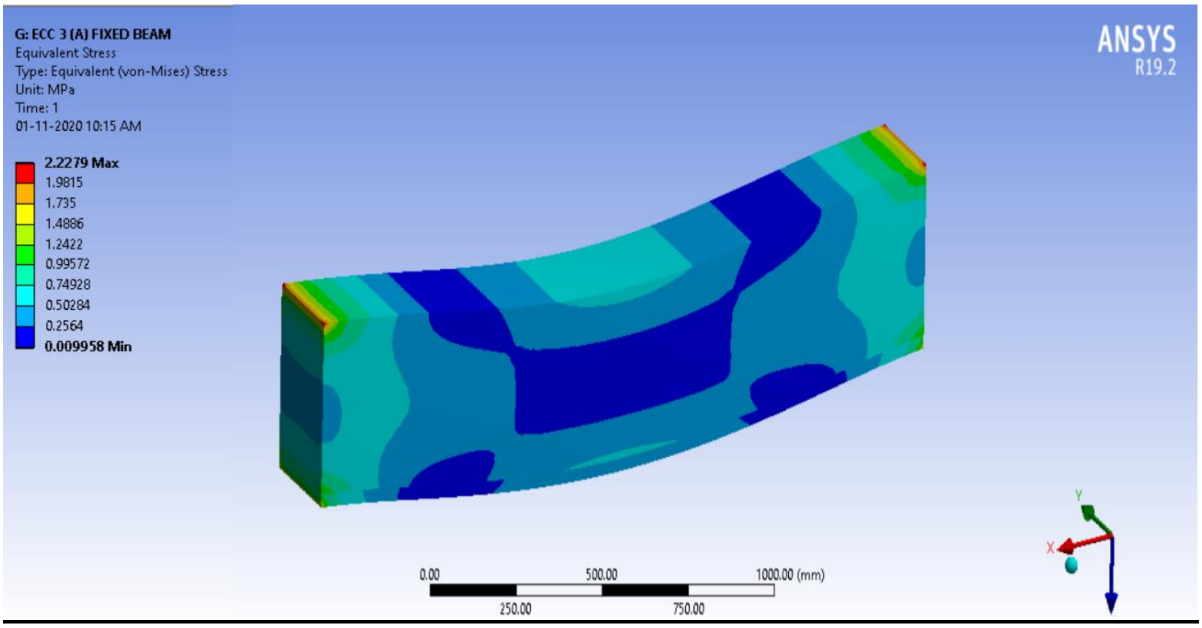


ECC 3 (A)

Deflection

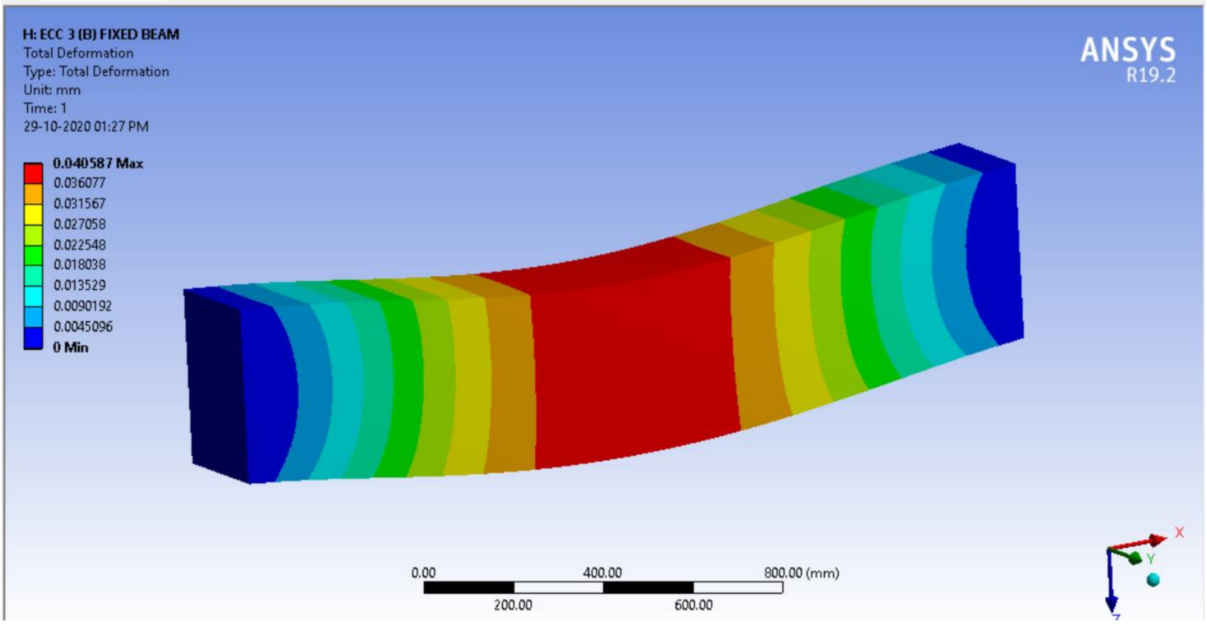


Stress

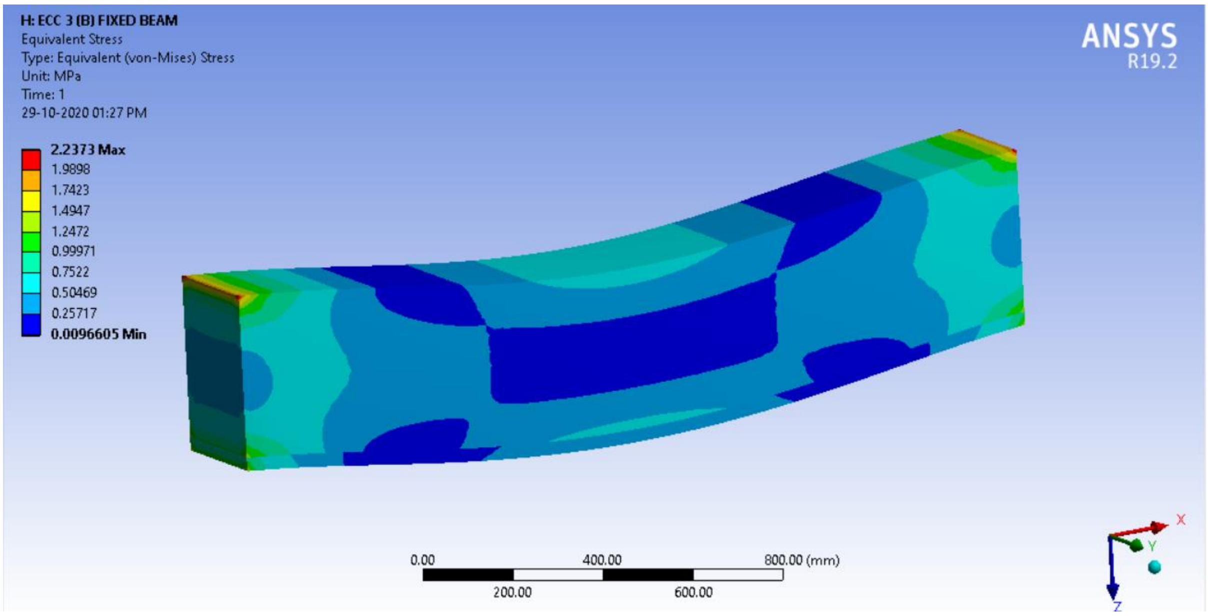


ECC 3 (B)

Deflection

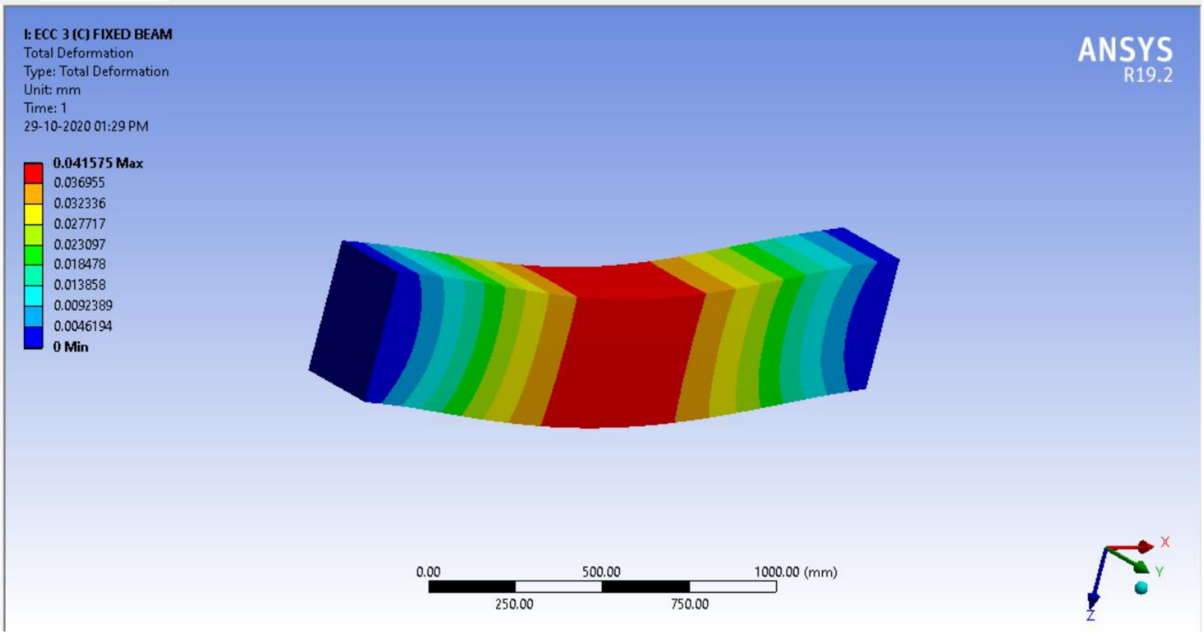


Stress

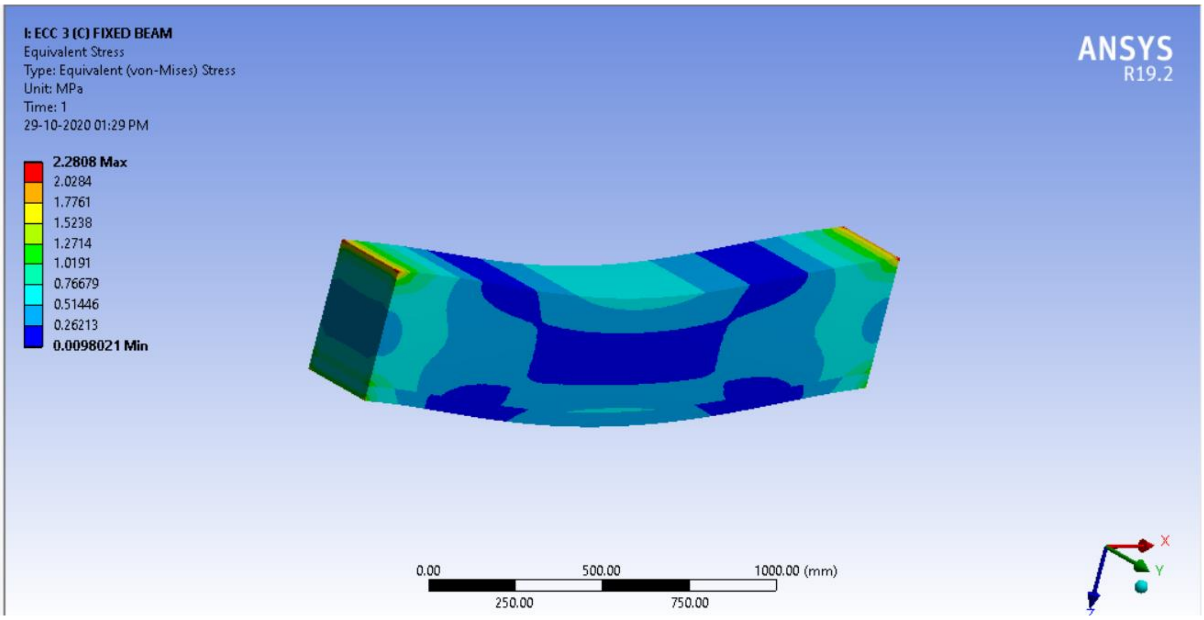


ECC 3 (C)

Deflection

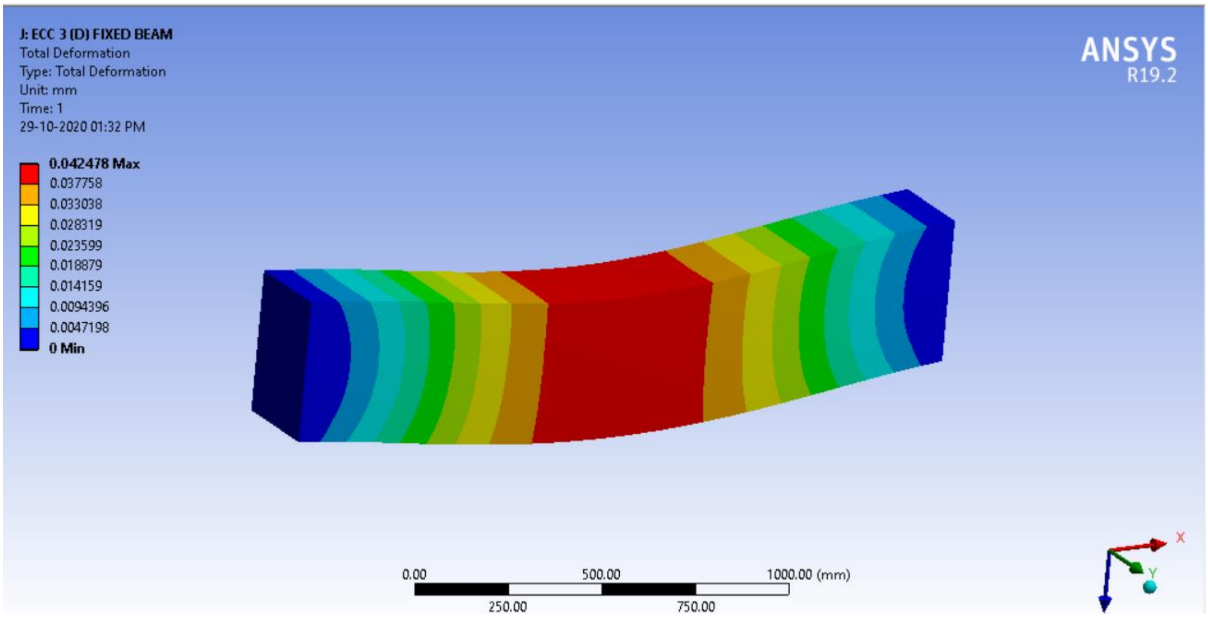

I: ECC 3 (C) FIXED BEAM
Total Deformation
Type: Total Deformation
Unit: mm
Time: 1
29-10-2020 01:29 PM

Stress

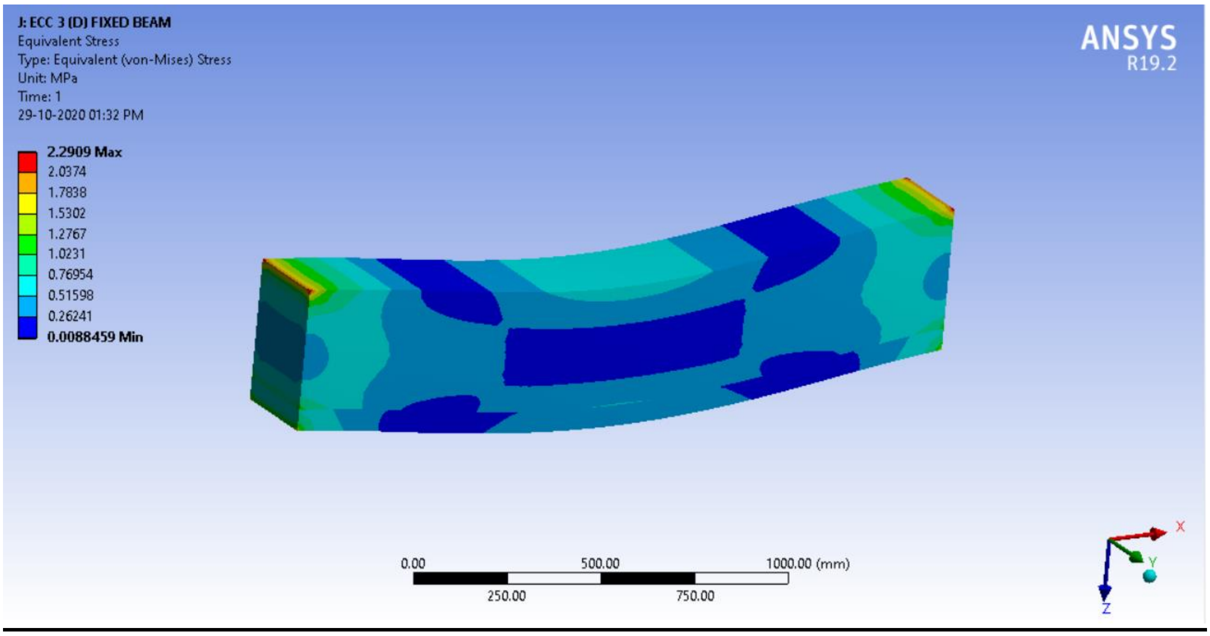

I: ECC 3 (C) FIXED BEAM
Equivalent Stress
Type: Equivalent (von-Mises) Stress
Unit: MPa
Time: 1
29-10-2020 01:29 PM

ECC 3 (D)

Deflection



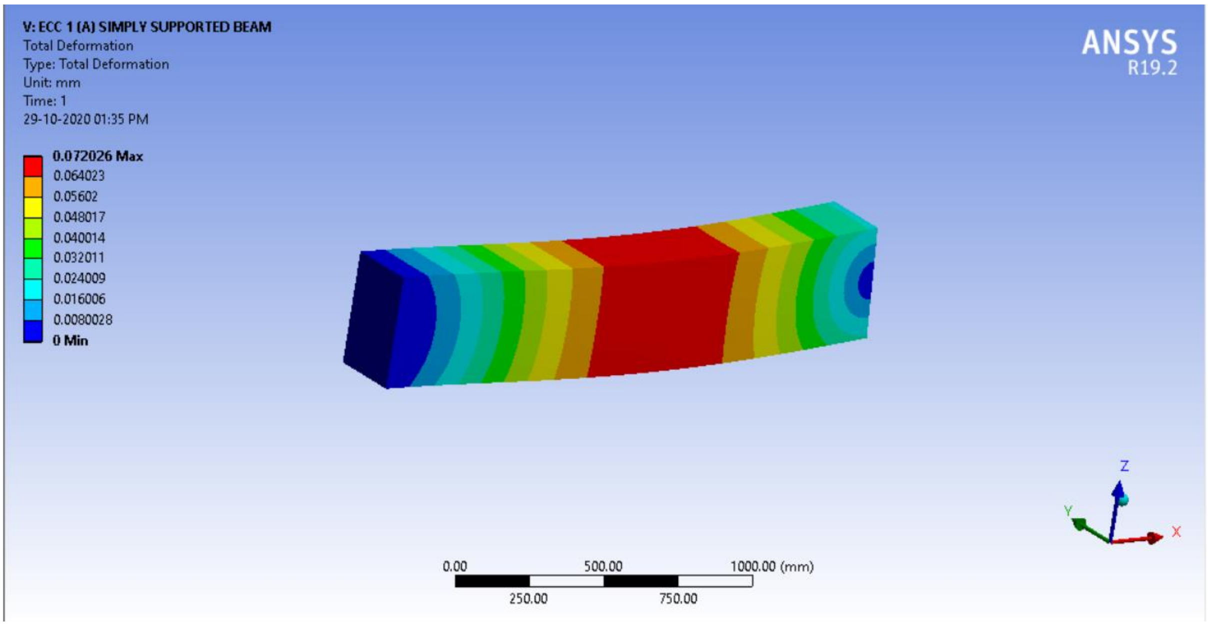
Stress



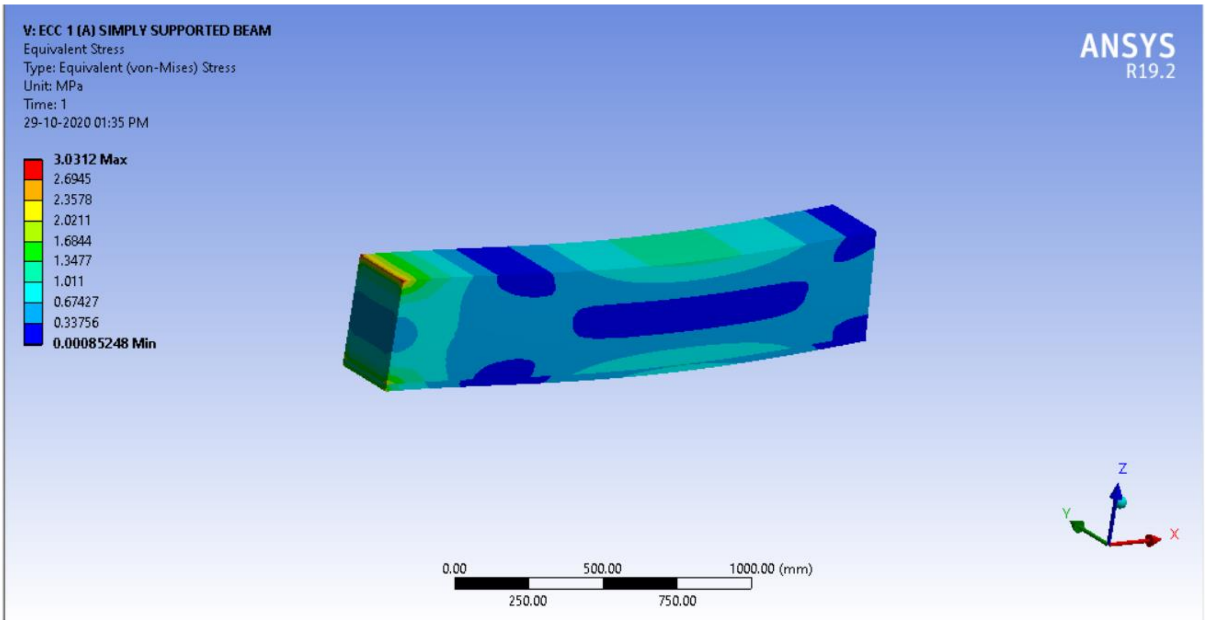
Deflection and Stress for Simply Supported Beams

ECC 1 (A)

Deflection

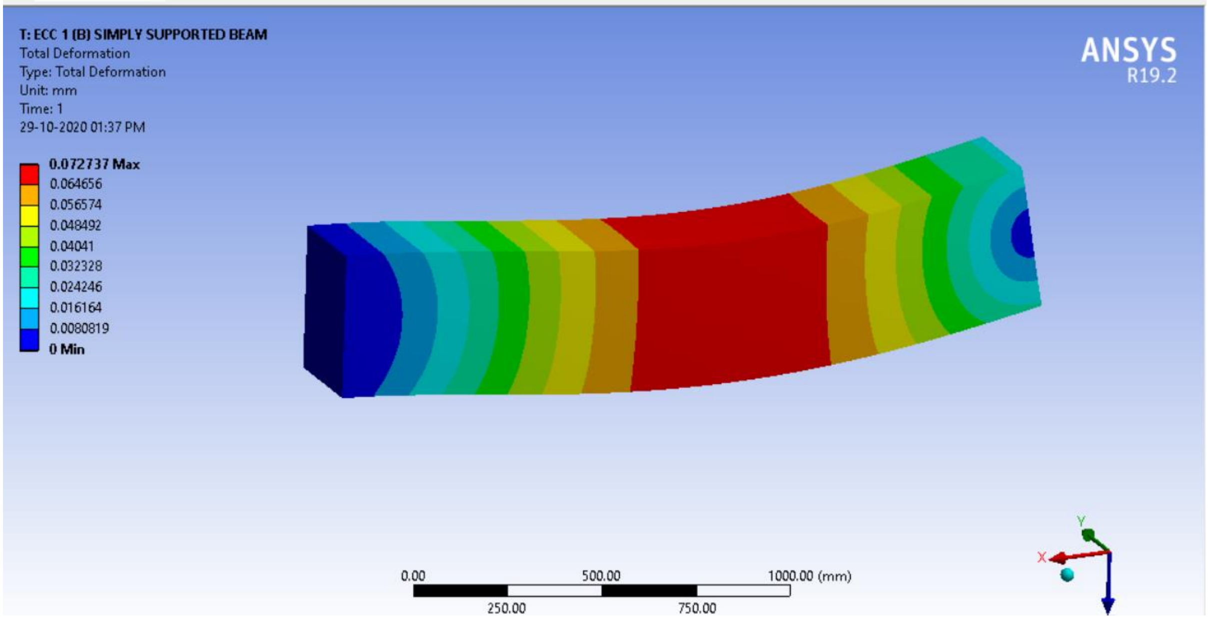


Stress

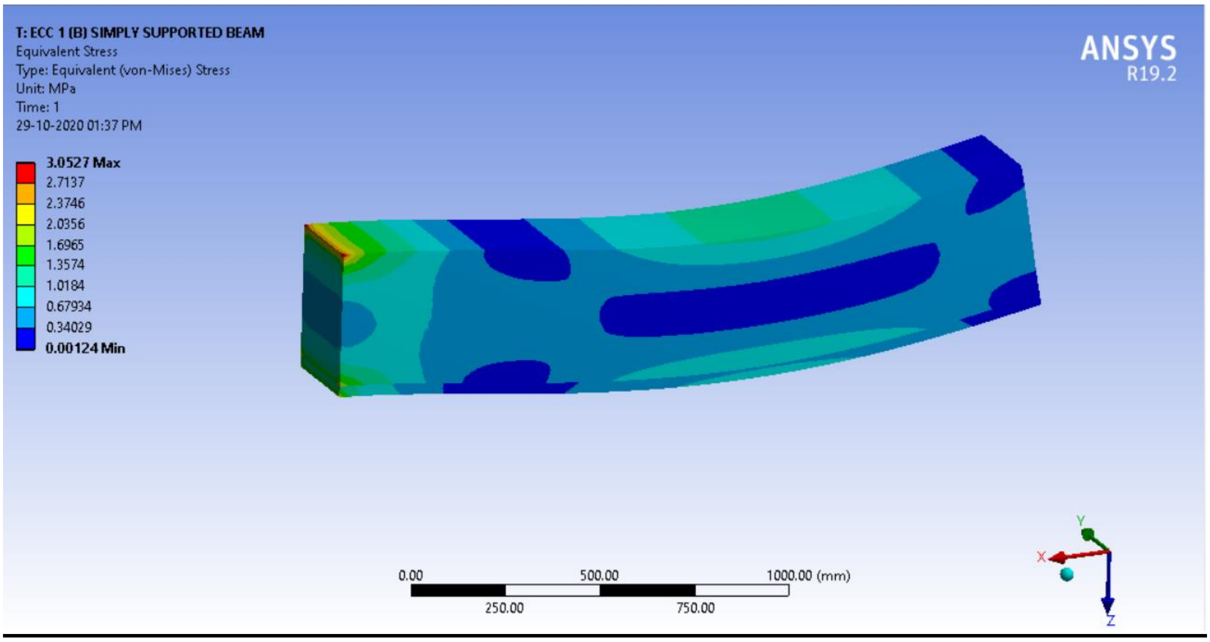


ECC 1 (B)

Deflection

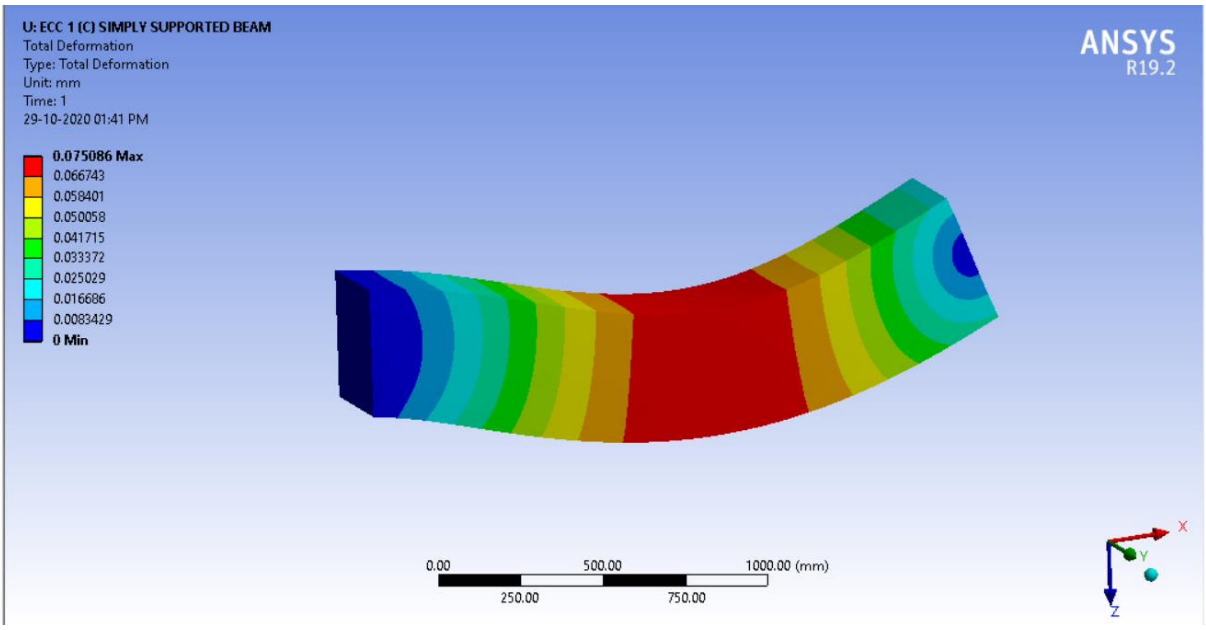


Stress

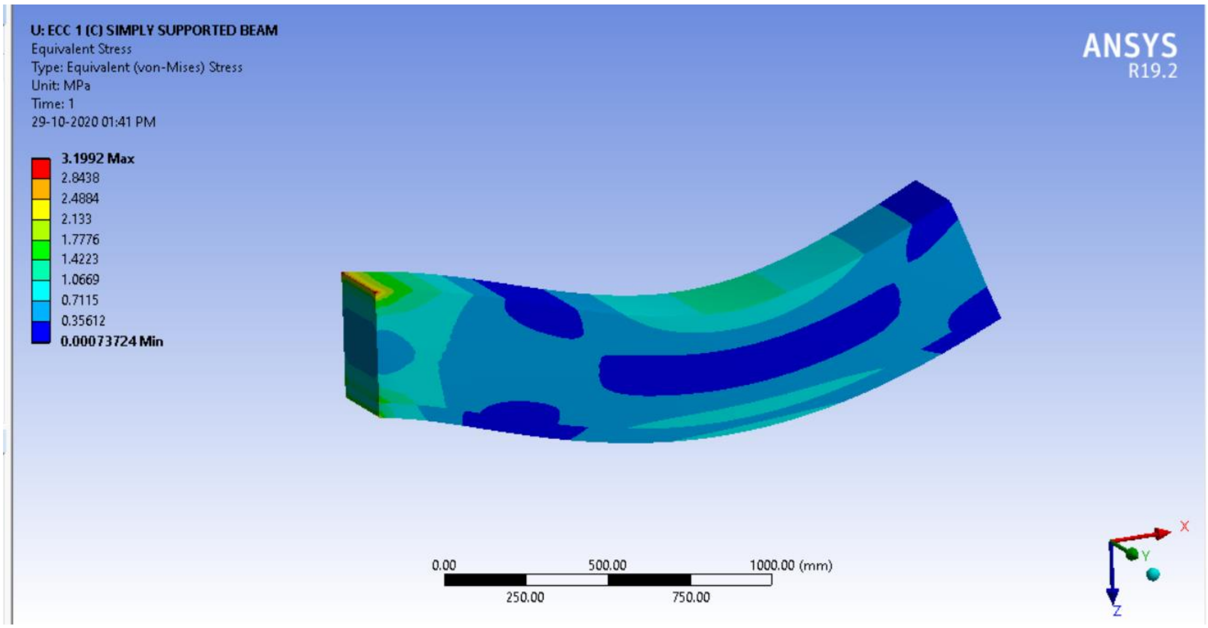


ECC 1 (C)

Deflection

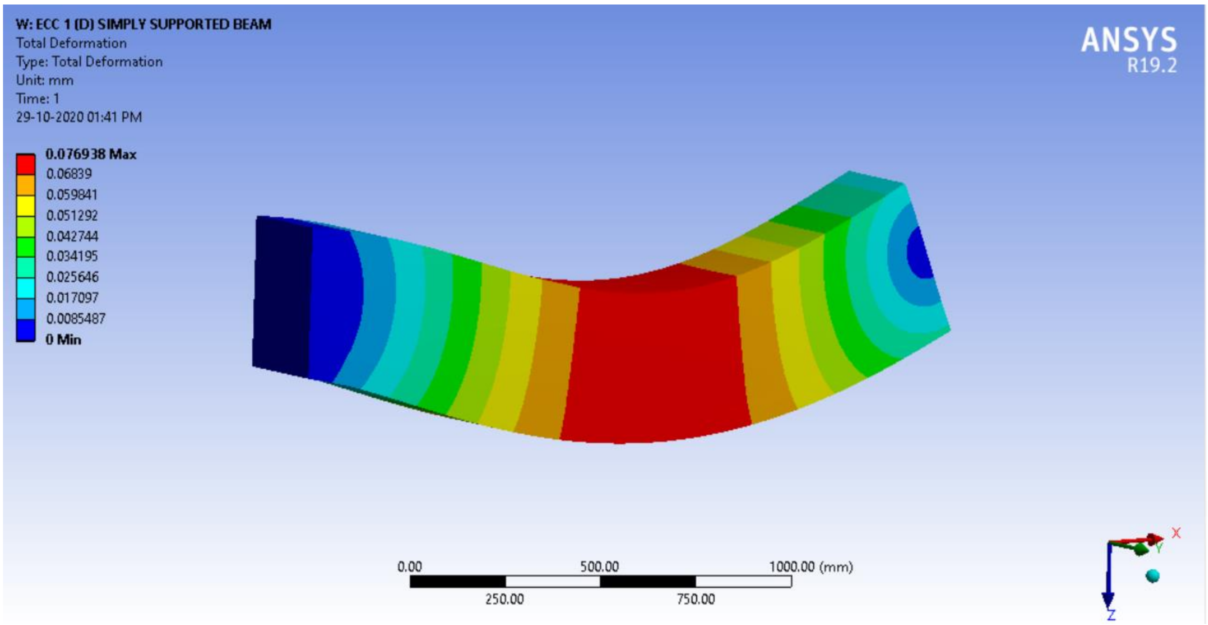

U: ECC 1 (C) SIMPLY SUPPORTED BEAM
Total Deformation
Type: Total Deformation
Unit: mm
Time: 1
29-10-2020 01:41 PM

Stress


U: ECC 1 (C) SIMPLY SUPPORTED BEAM
Equivalent Stress
Type: Equivalent (von-Mises) Stress
Unit: MPa
Time: 1
29-10-2020 01:41 PM

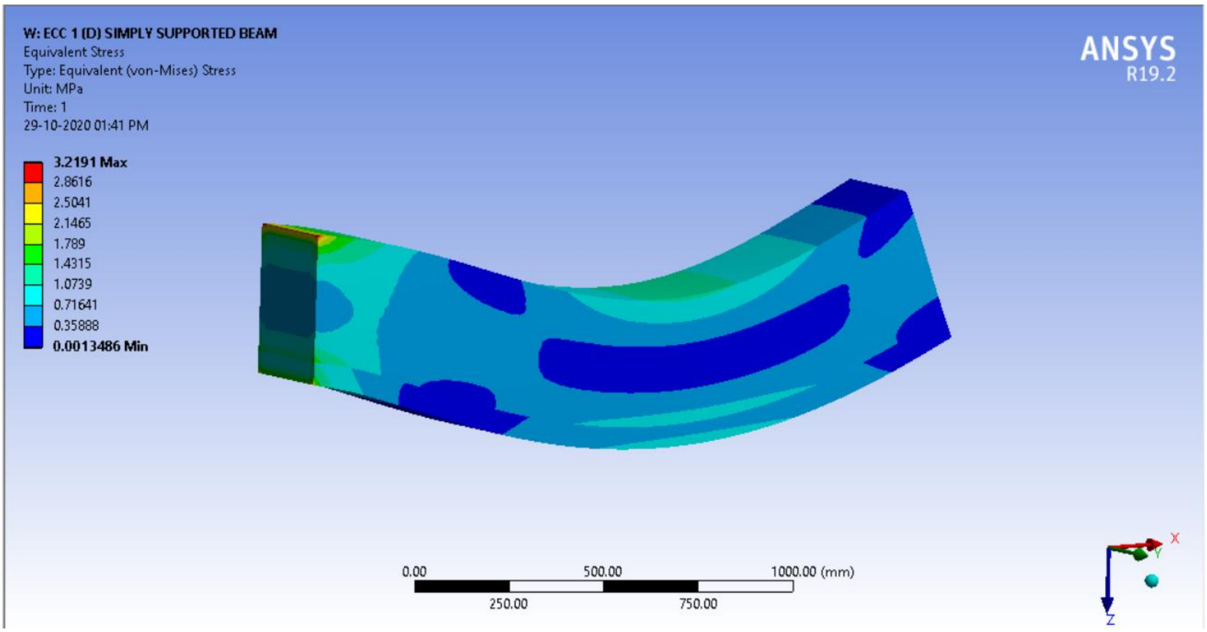
ECC 1 (D)

Deflection



W: ECC 1 (D) SIMPLY SUPPORTED BEAM
Total Deformation
Type: Total Deformation
Unit: mm
Time: 1
29-10-2020 01:41 PM

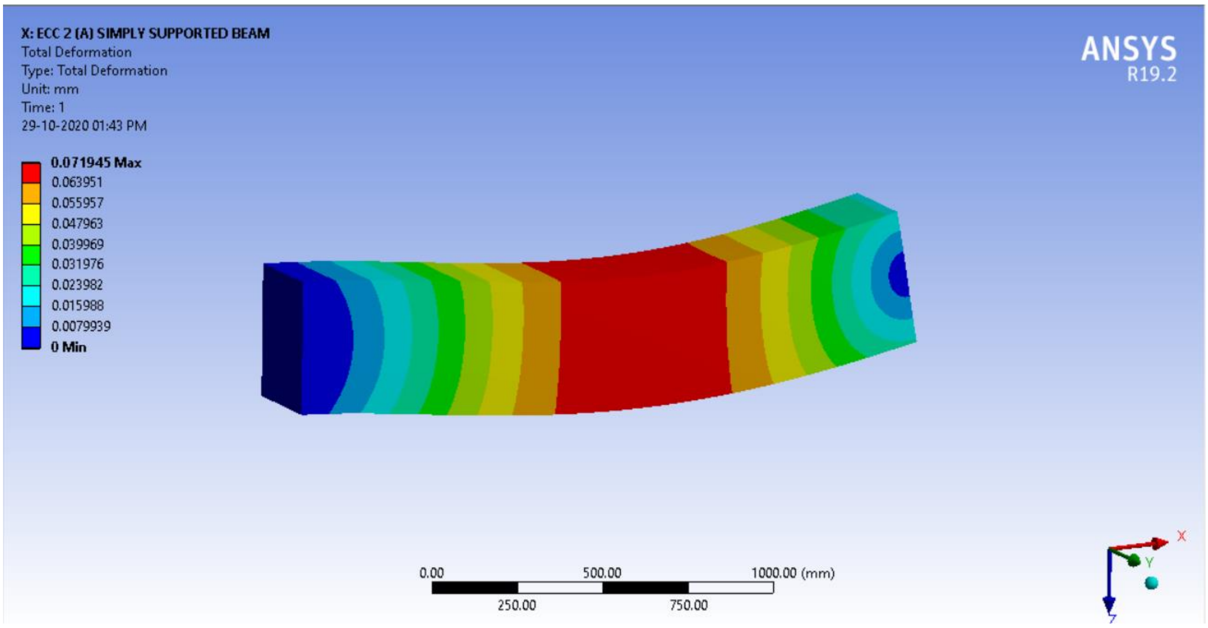
Stress



W: ECC 1 (D) SIMPLY SUPPORTED BEAM
Equivalent Stress
Type: Equivalent (von-Mises) Stress
Unit: MPa
Time: 1
29-10-2020 01:41 PM

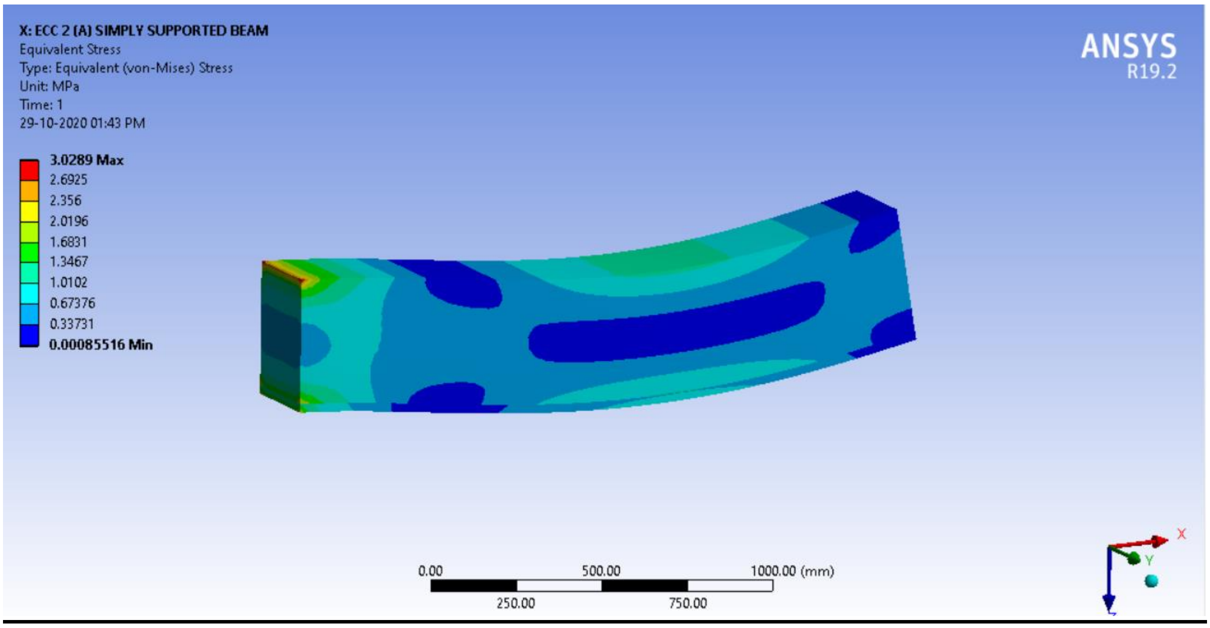
ECC 2 (A)

Deflection



X: ECC 2 (A) SIMPLY SUPPORTED BEAM
Total Deformation
Type: Total Deformation
Unit: mm
Time: 1
29-10-2020 01:43 PM

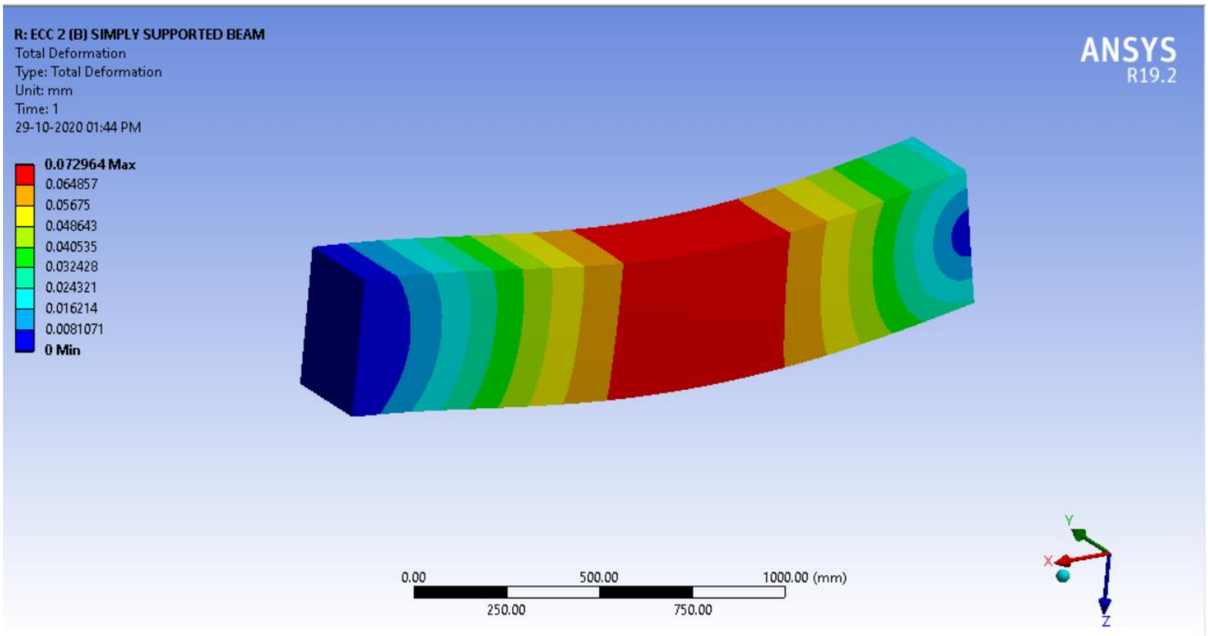
Stress



X: ECC 2 (A) SIMPLY SUPPORTED BEAM
Equivalent Stress
Type: Equivalent (von-Mises) Stress
Unit: MPa
Time: 1
29-10-2020 01:43 PM

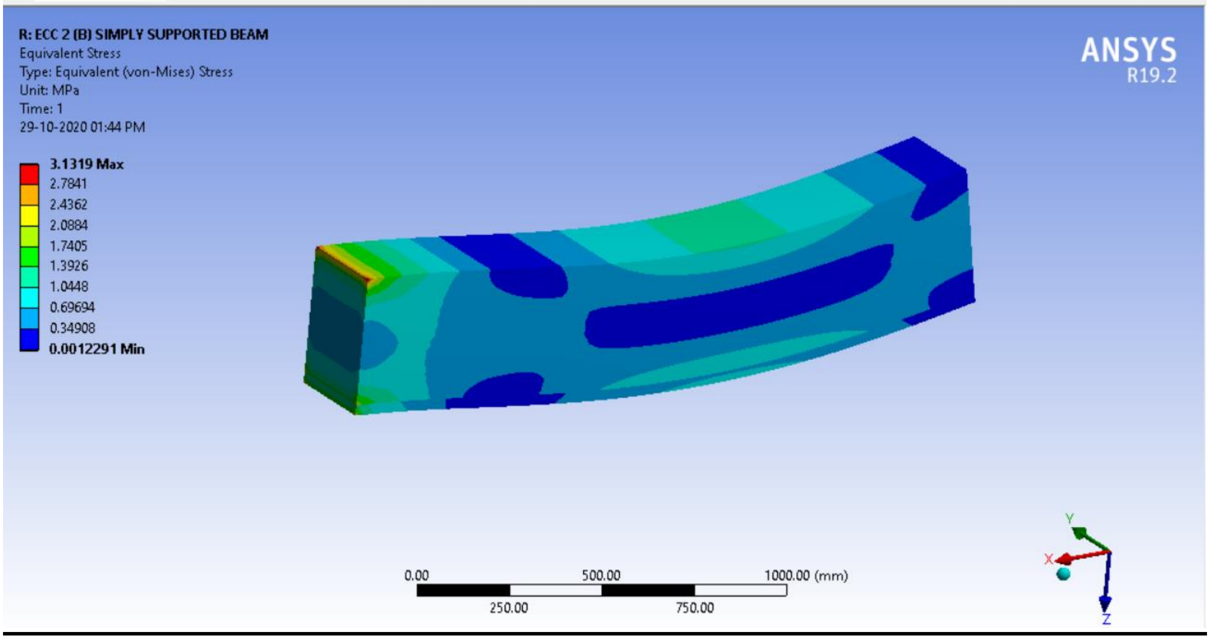
ECC 2 (B)

Deflection



R: ECC 2 (B) SIMPLY SUPPORTED BEAM
Total Deformation
Type: Total Deformation
Unit: mm
Time: 1
29-10-2020 01:44 PM

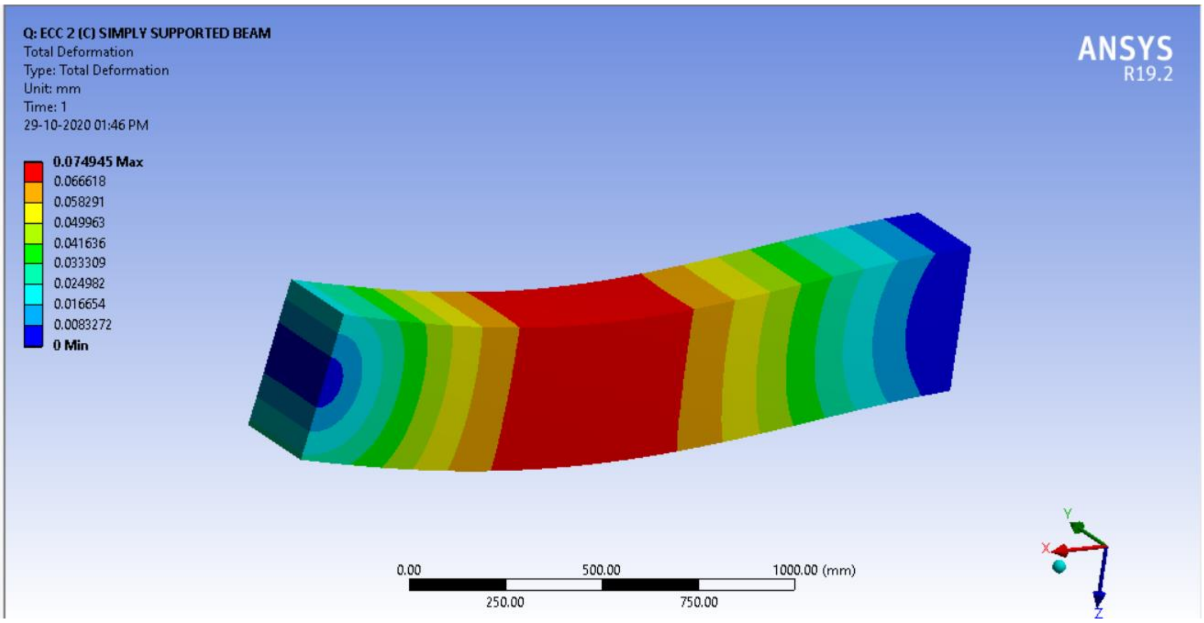
Stress



R: ECC 2 (B) SIMPLY SUPPORTED BEAM
Equivalent Stress
Type: Equivalent (von-Mises) Stress
Unit: MPa
Time: 1
29-10-2020 01:44 PM

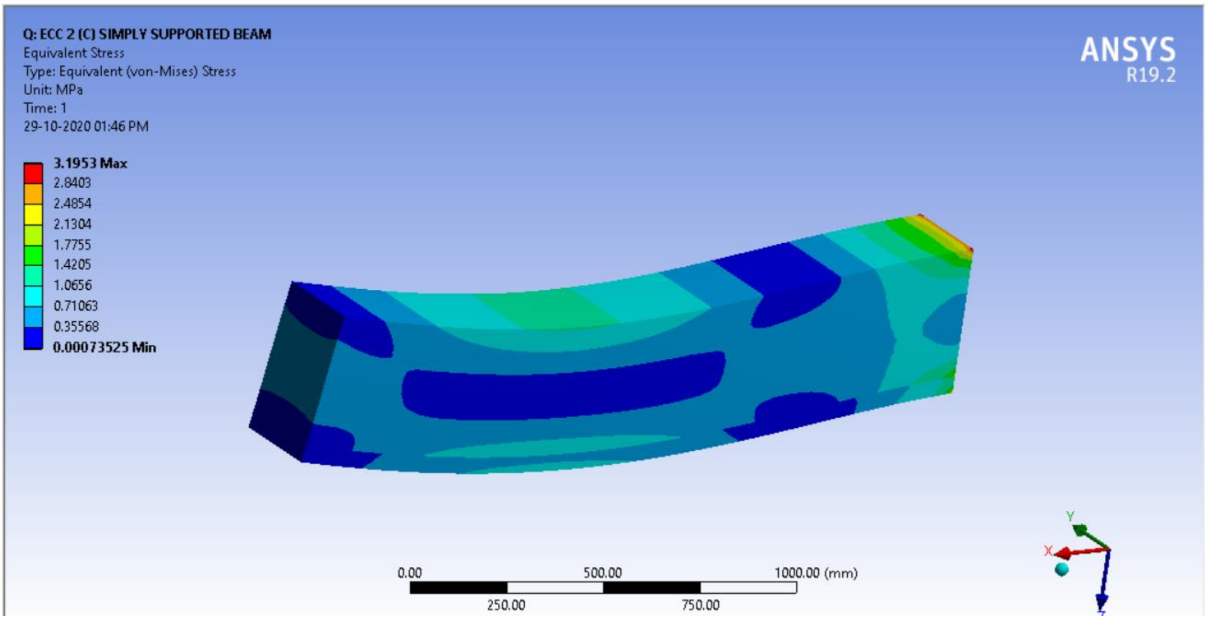
ECC 2 (C)

Deflection



Q: ECC 2 (C) SIMPLY SUPPORTED BEAM
Total Deformation
Type: Total Deformation
Unit: mm
Time: 1
29-10-2020 01:46 PM

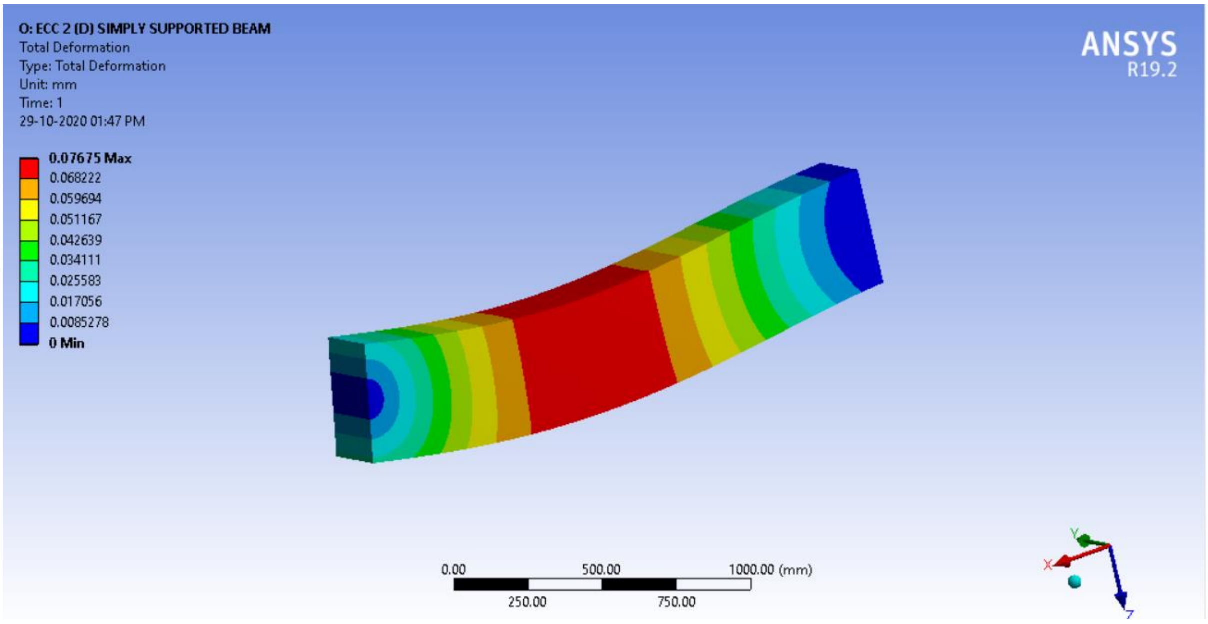
Stress



Q: ECC 2 (C) SIMPLY SUPPORTED BEAM
Equivalent Stress
Type: Equivalent (von-Mises) Stress
Unit: MPa
Time: 1
29-10-2020 01:46 PM

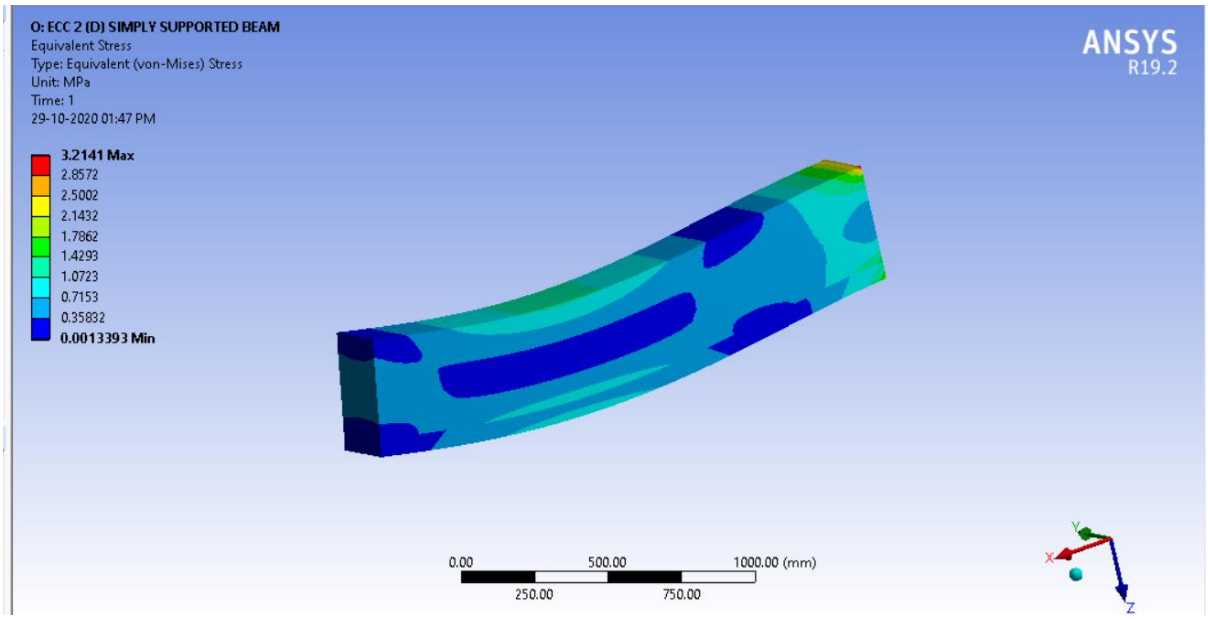
ECC 2 (D)

Deflection



O: ECC 2 (D) SIMPLY SUPPORTED BEAM
Total Deformation
Type: Total Deformation
Unit: mm
Time: 1
29-10-2020 01:47 PM

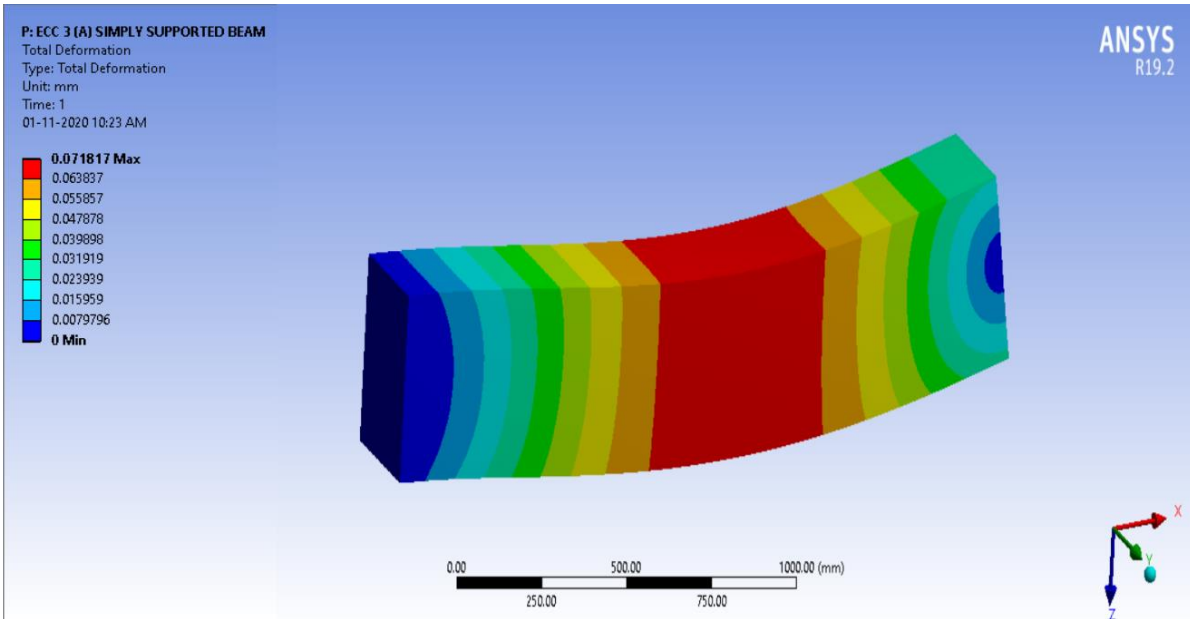
Stress



O: ECC 2 (D) SIMPLY SUPPORTED BEAM
Equivalent Stress
Type: Equivalent (von-Mises) Stress
Unit: MPa
Time: 1
29-10-2020 01:47 PM

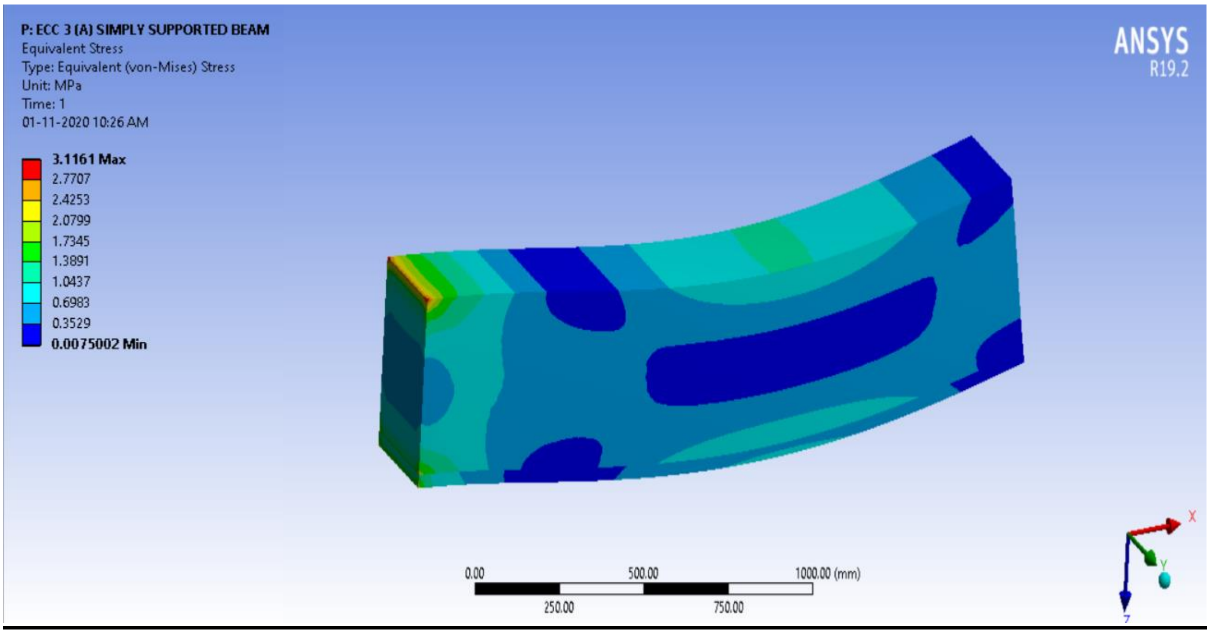
ECC 3 (A)

Deflection



P: ECC 3 (A) SIMPLY SUPPORTED BEAM
Total Deformation
Type: Total Deformation
Unit: mm
Time: 1
01-11-2020 10:23 AM

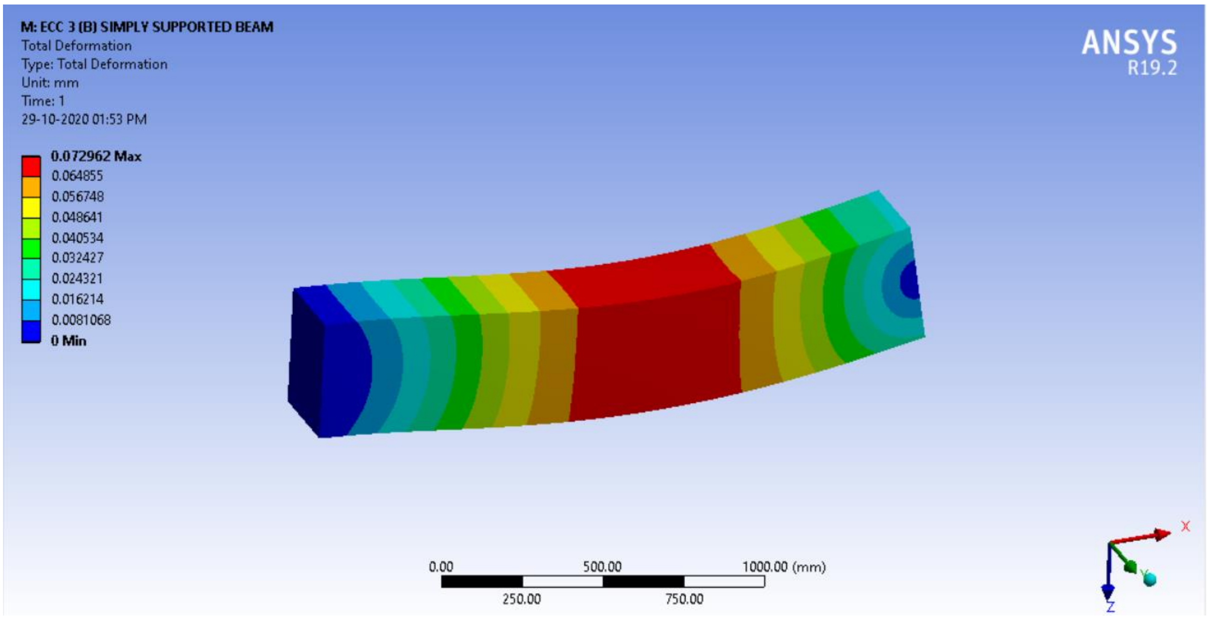
Stress



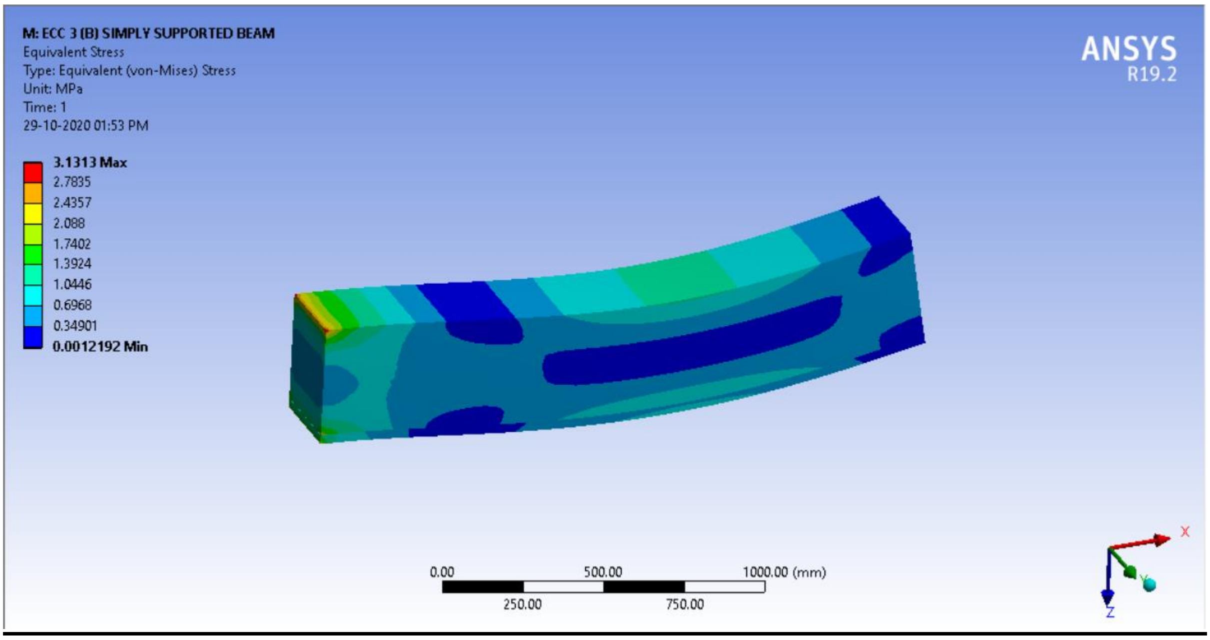
P: ECC 3 (A) SIMPLY SUPPORTED BEAM
Equivalent Stress
Type: Equivalent (von-Mises) Stress
Unit: MPa
Time: 1
01-11-2020 10:26 AM

ECC 3 (B)

Deflection

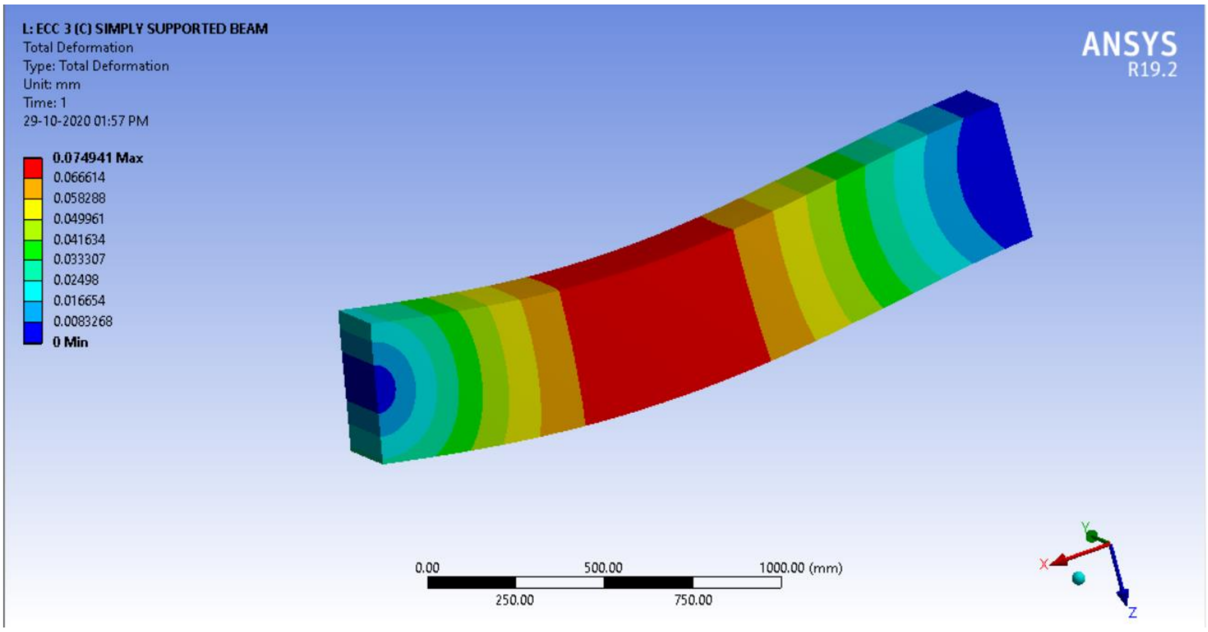


Stress

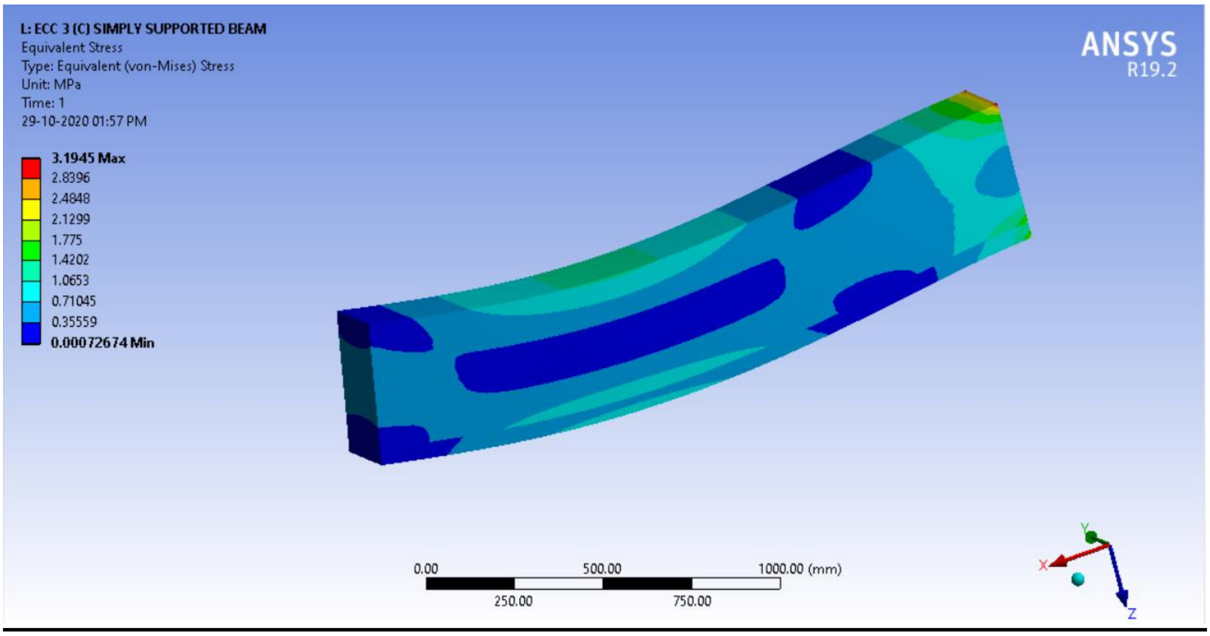


ECC 3 (C)

Deflection

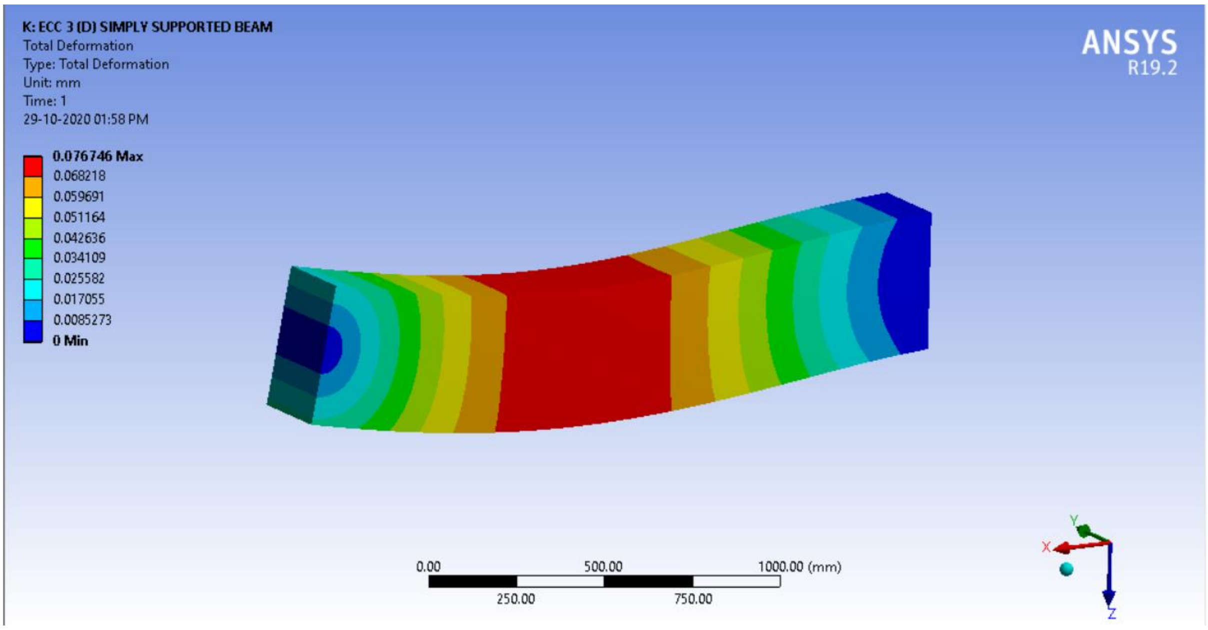


Stress



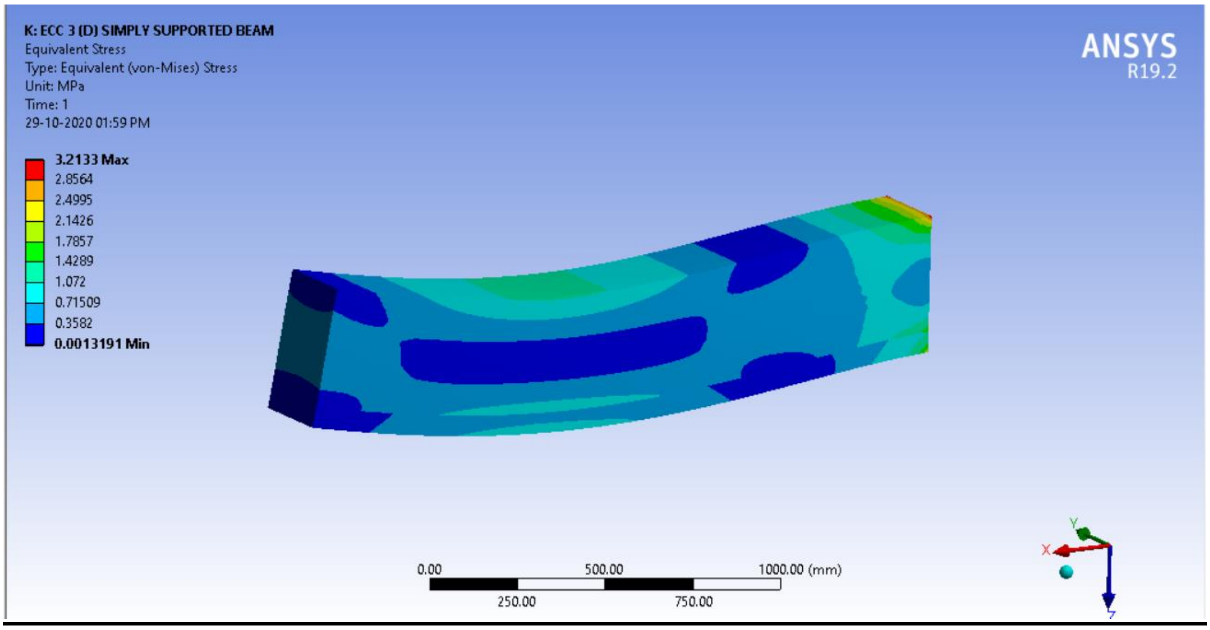
ECC 3 (D)

Deflection



K: ECC 3 (D) SIMPLY SUPPORTED BEAM
Total Deformation
Type: Total Deformation
Unit: mm
Time: 1
29-10-2020 01:58 PM

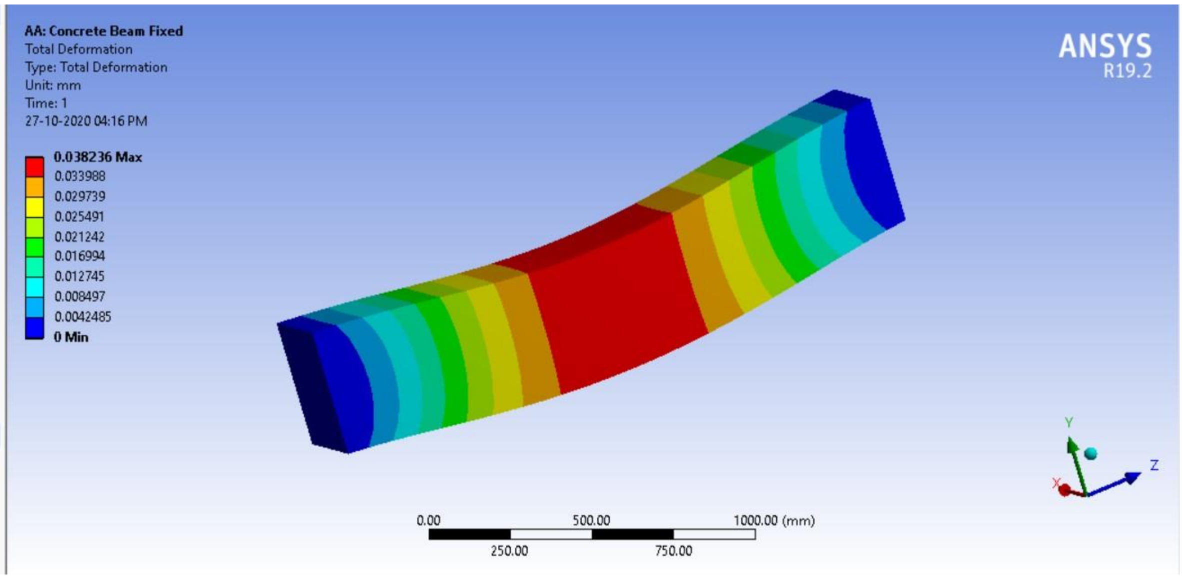
Stress



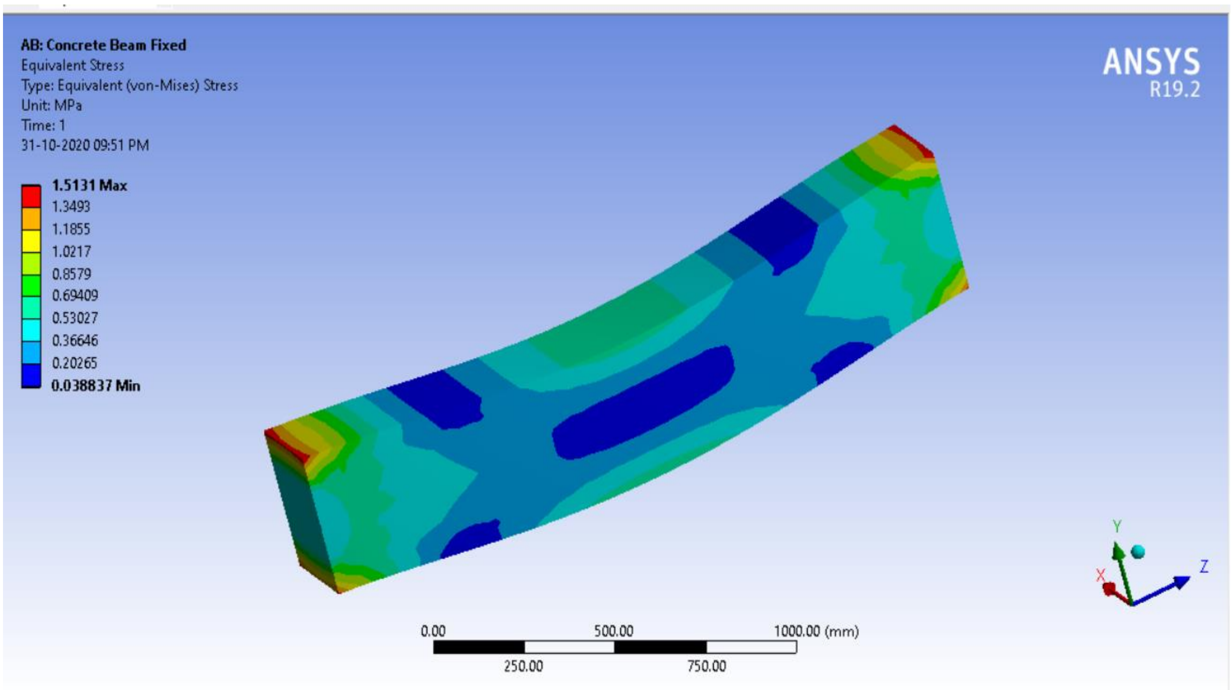
K: ECC 3 (D) SIMPLY SUPPORTED BEAM
Equivalent Stress
Type: Equivalent (von-Mises) Stress
Unit: MPa
Time: 1
29-10-2020 01:59 PM

Concrete Beam (Fixed)

Deflection

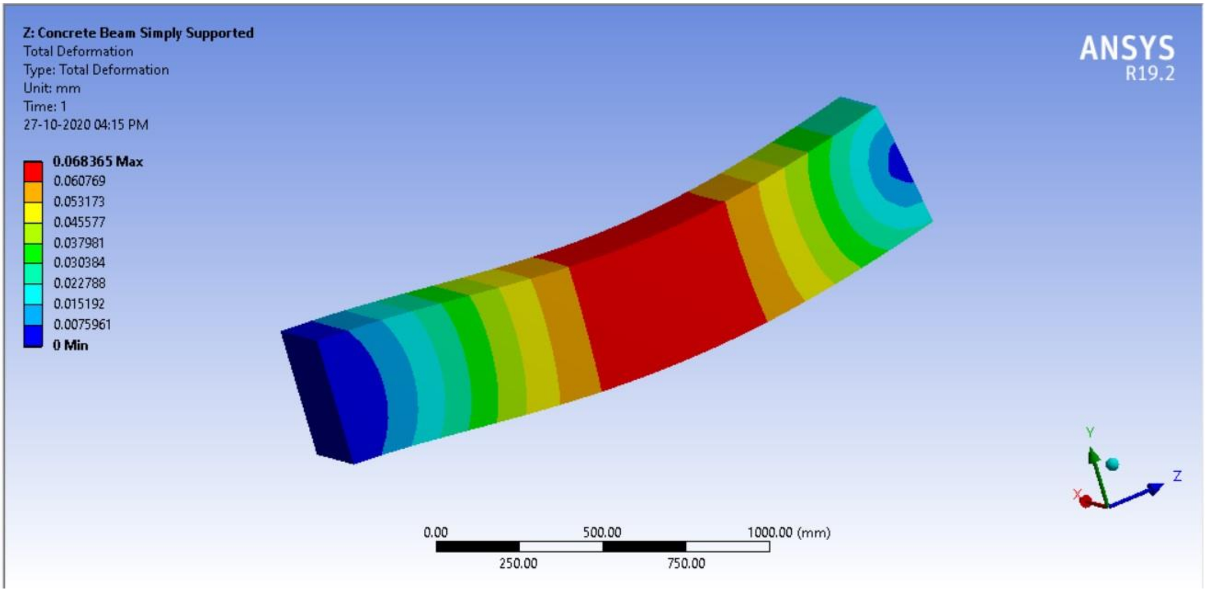


Stress

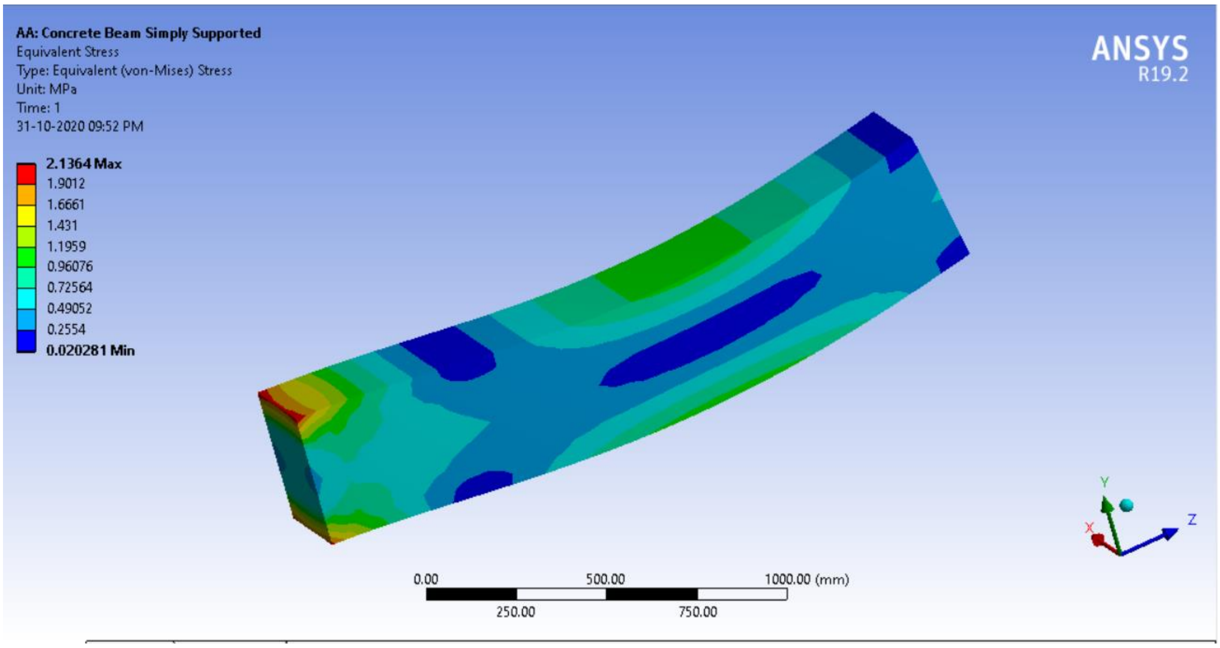


Concrete Beam (Simply Supported Beam)

Deflection

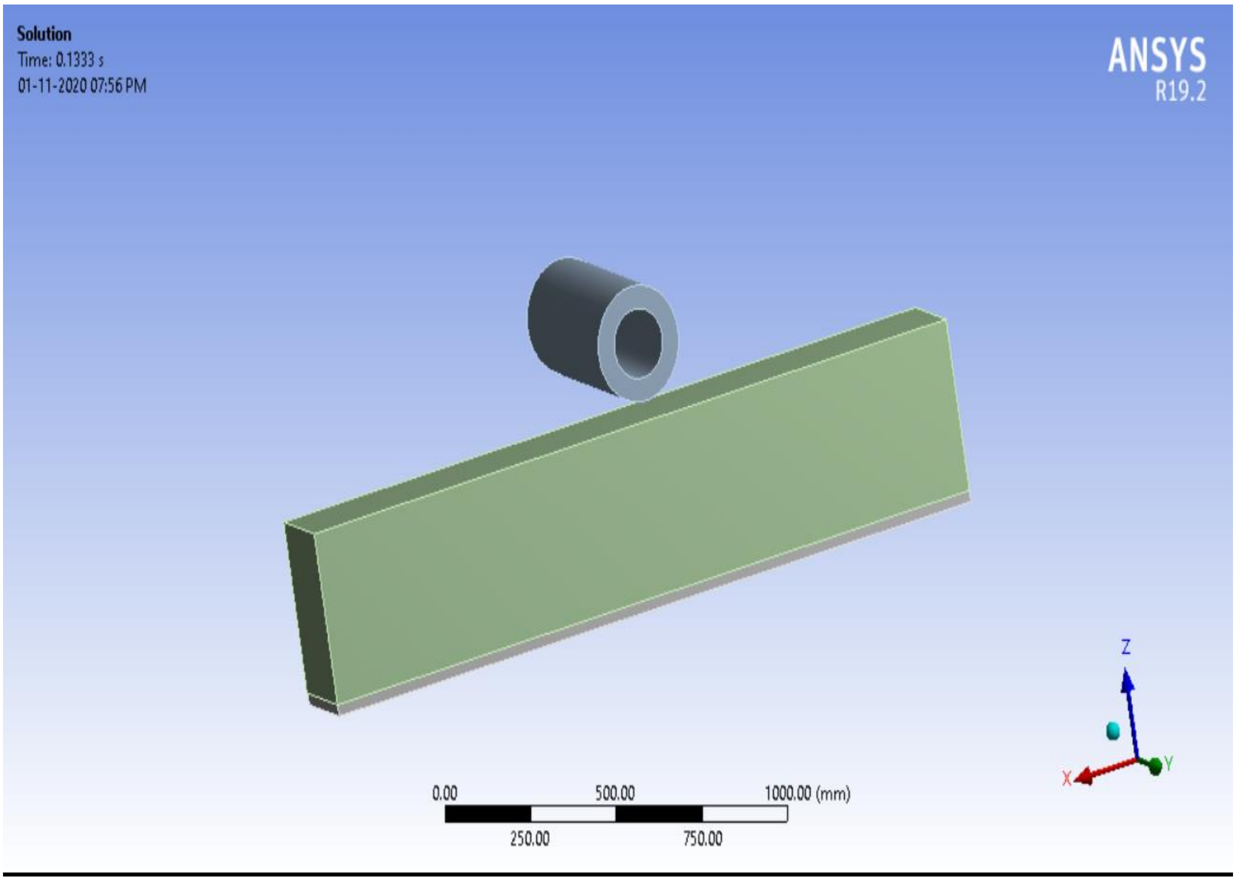


Stress



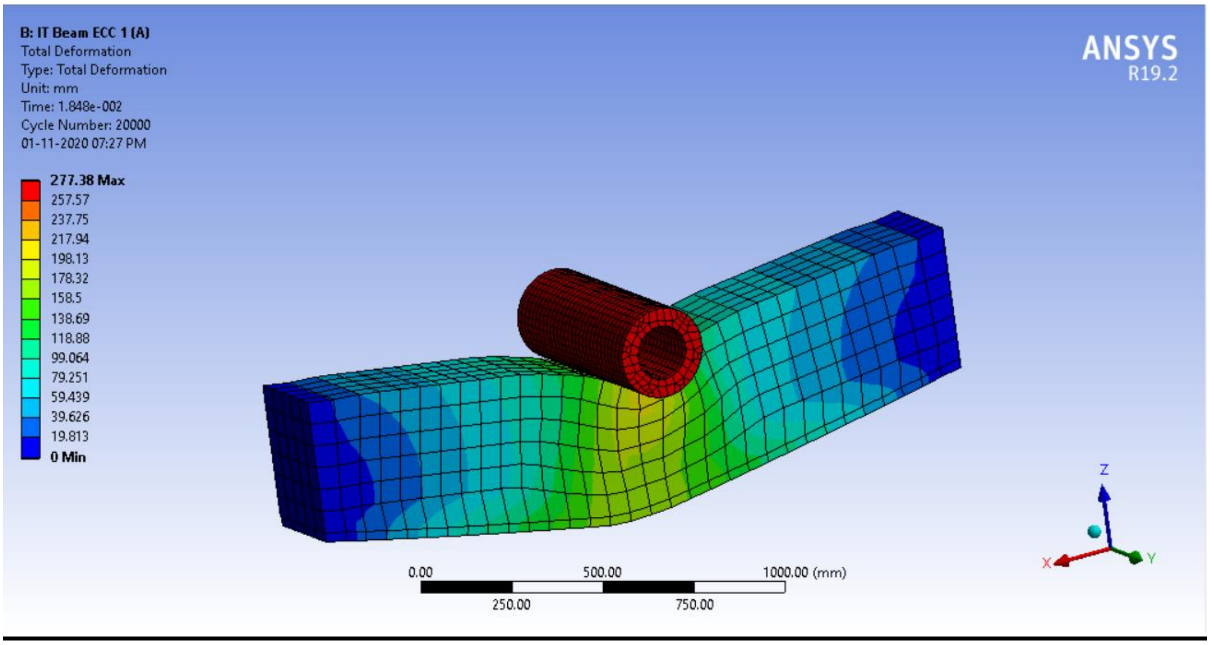
7.2 Impact Loading Performance Analysis of ECC composites using ANSYS

In the impact loading analysis of the ECC layered beam, the ECC specimens of fixed beams were used and a hollow cylindrical tube was used as an impactor. The impactor was being free fall at a height of 300 mm and at a velocity of 1500 mm/s.
The deflection in the beam is as follows:



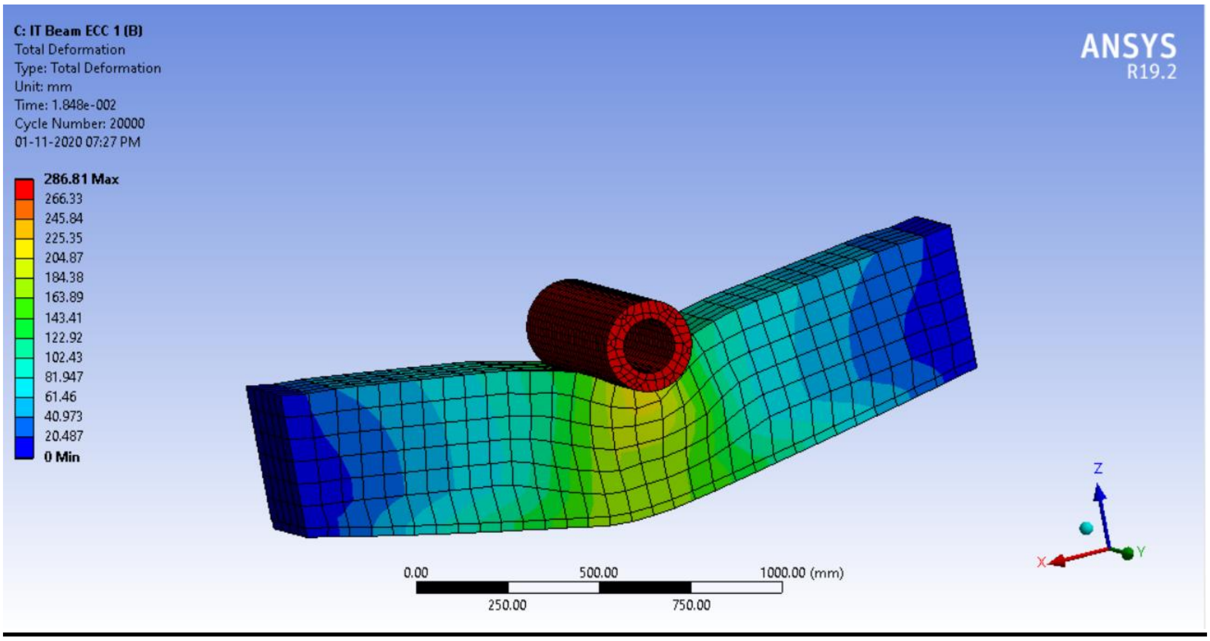
ECC 1 (A)

Deflection



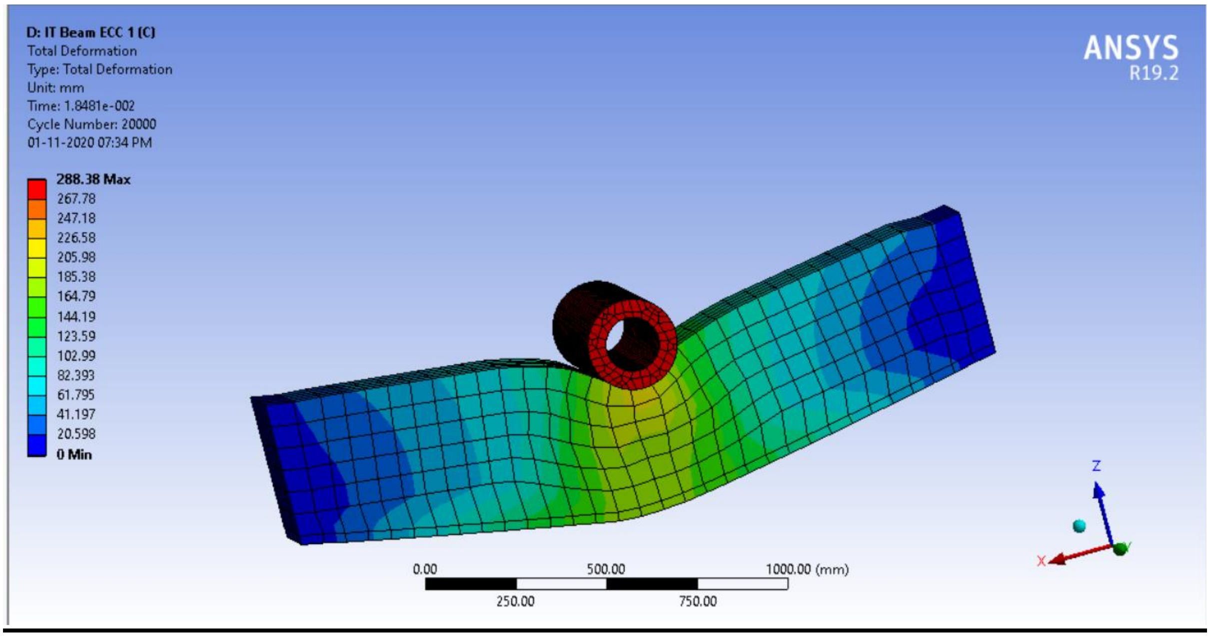
ECC 1 (B)

Deflection



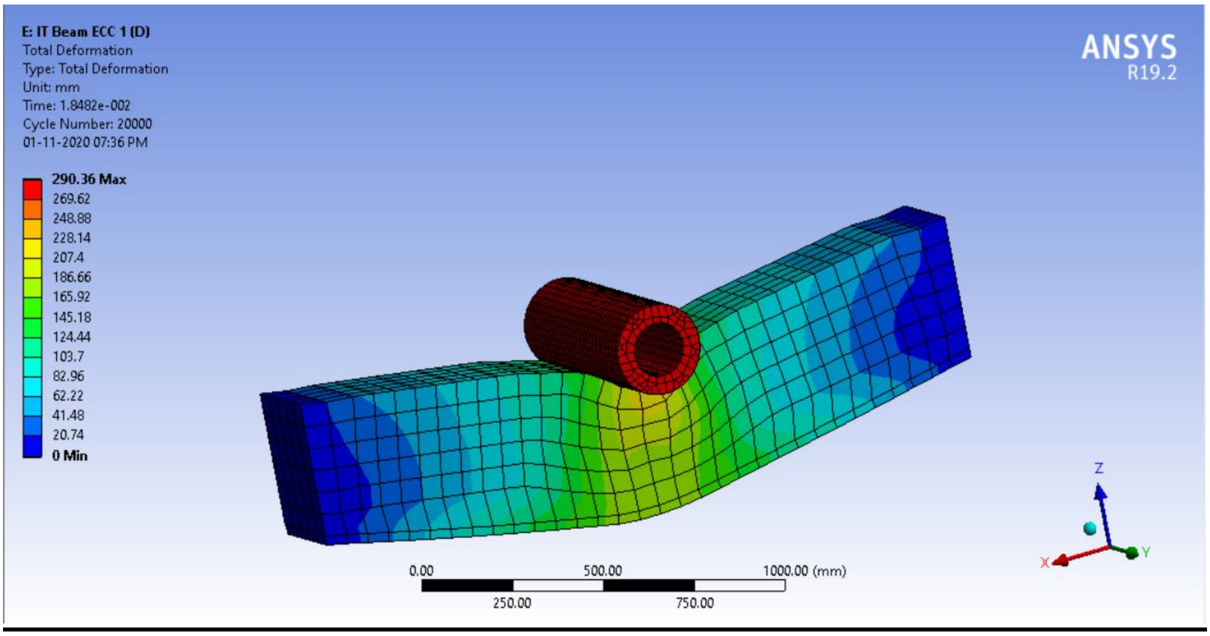
ECC 1 (C)

Deflection



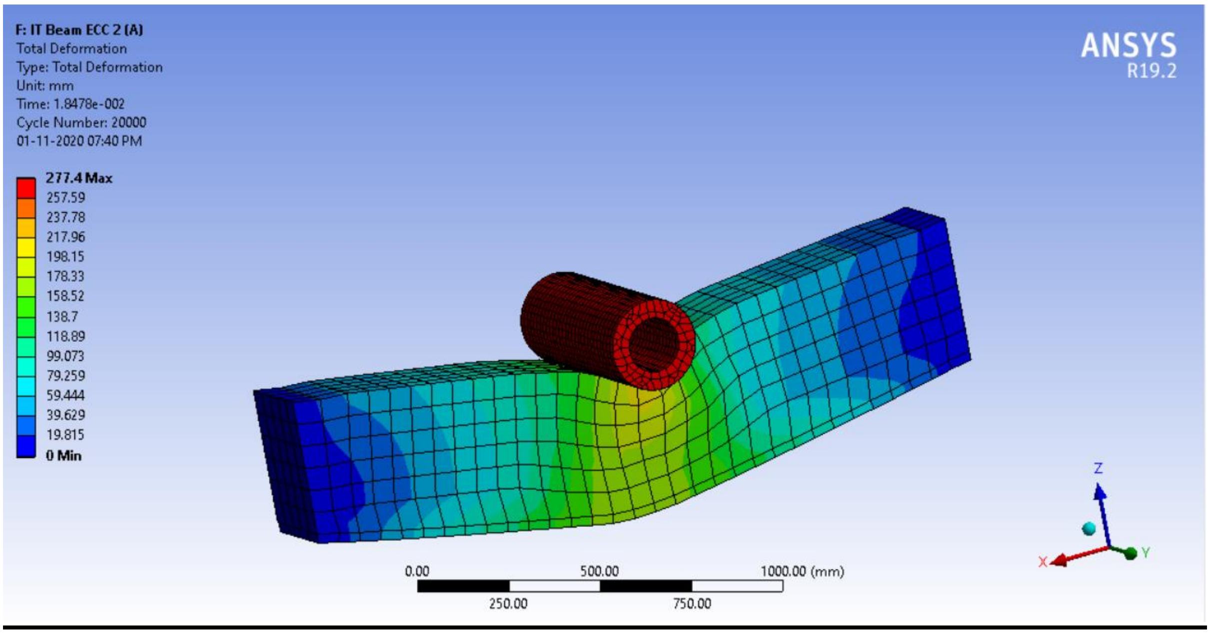
ECC 1 (D)

Deflection



ECC 2 (A)

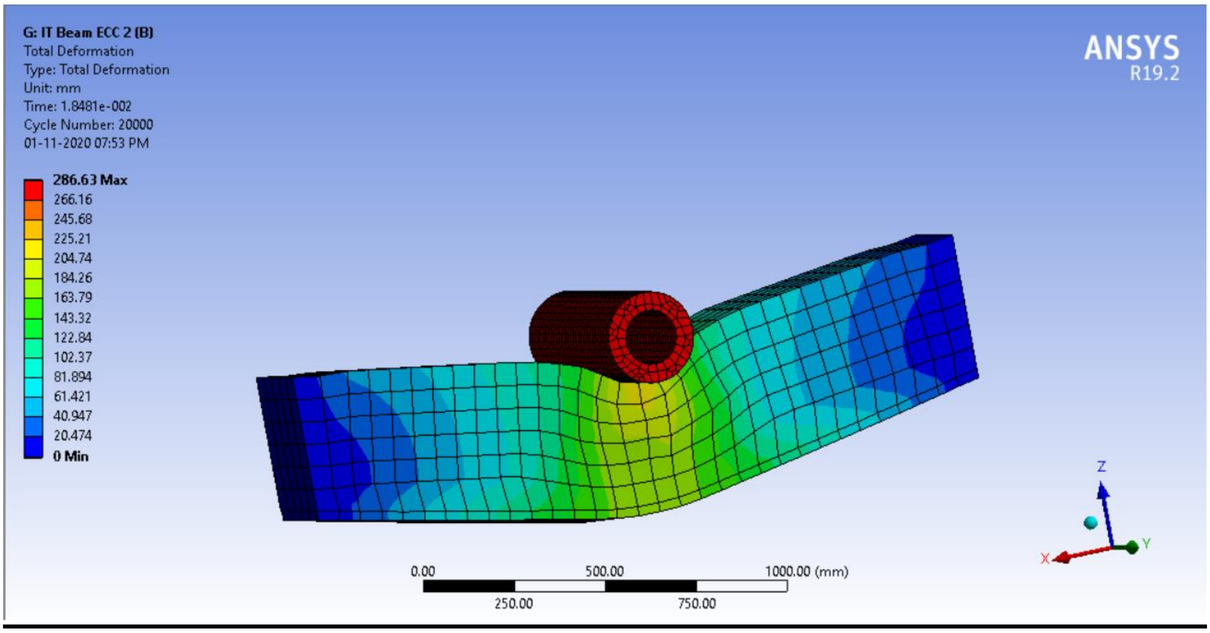
Deflection



F: IT Beam ECC 2 (A)
Total Deformation
Type: Total Deformation
Unit: mm
Time: 1.8478e-002
Cycle Number: 20000
01-11-2020 07:40 PM

ECC 2 (B)

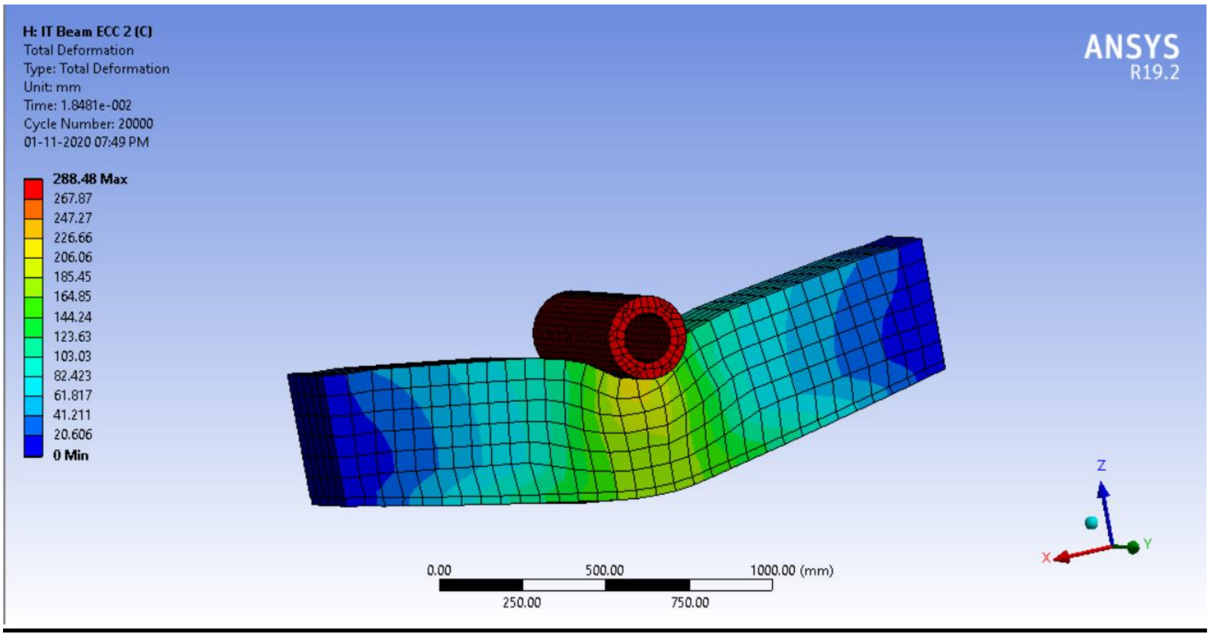
Deflection



G: IT Beam ECC 2 (B)
Total Deformation
Type: Total Deformation
Unit: mm
Time: 1.8481e-002
Cycle Number: 20000
01-11-2020 07:53 PM

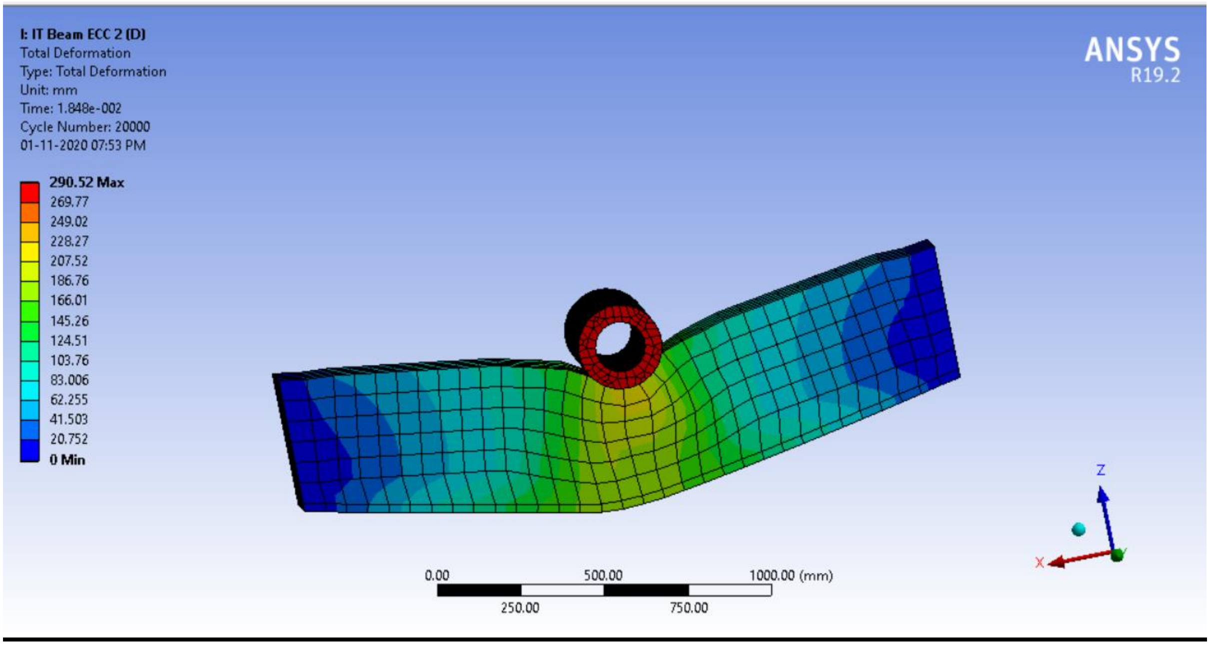
ECC 2 (C)

Deflection



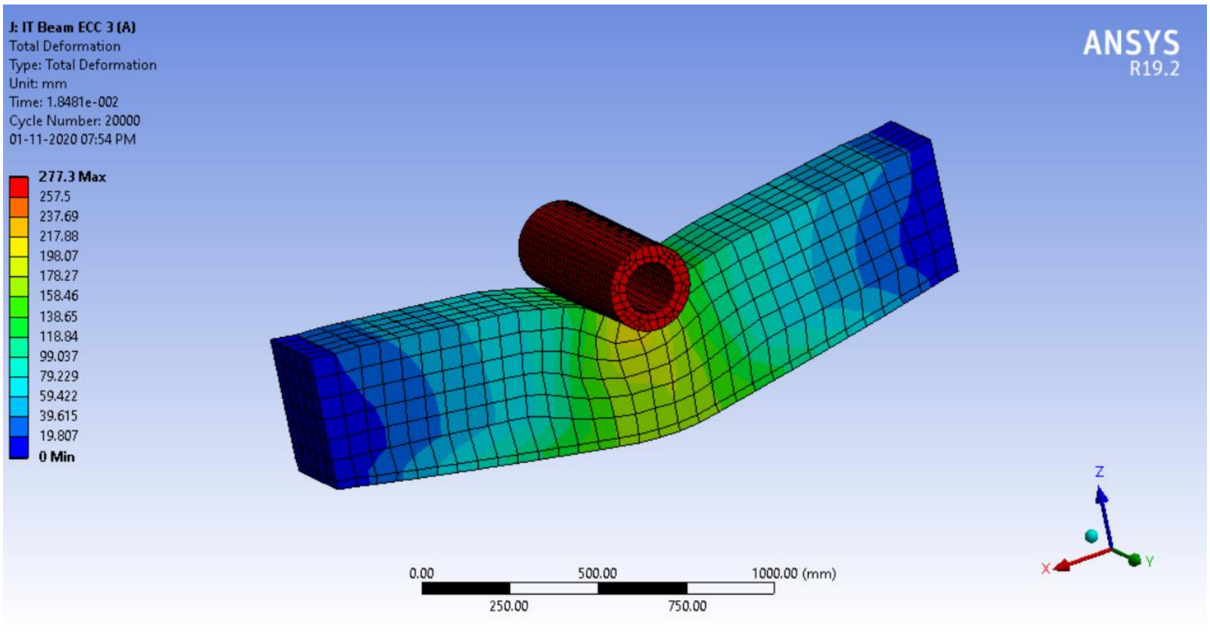
ECC 2 (D)

Deflection



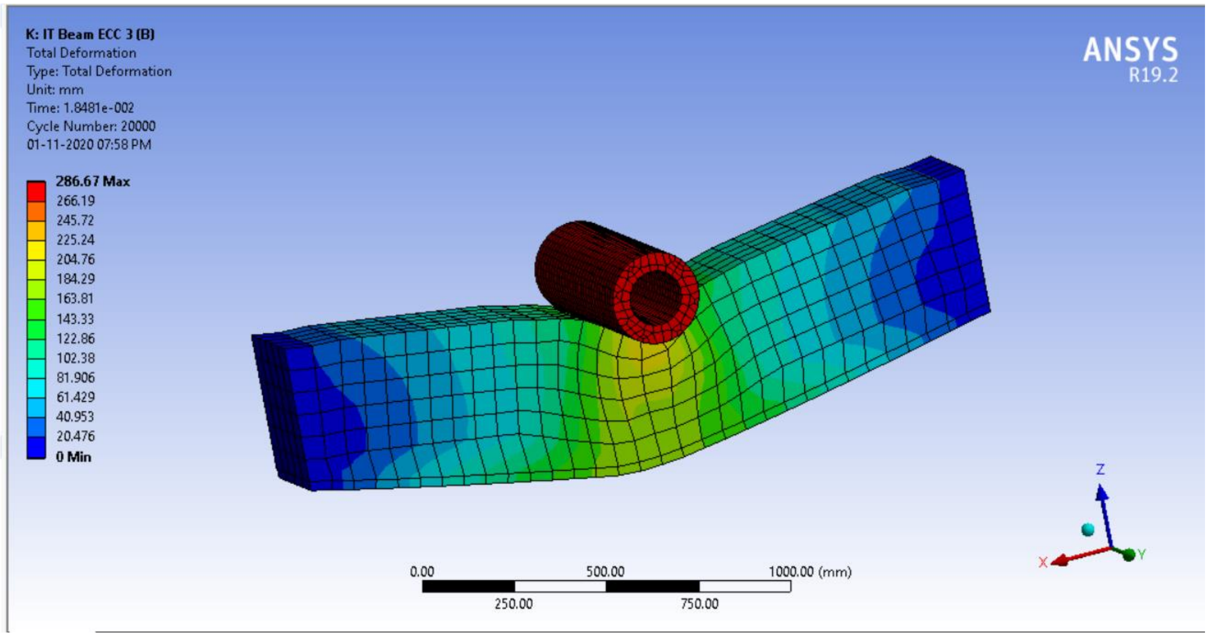
ECC 3 (A)

Deflection



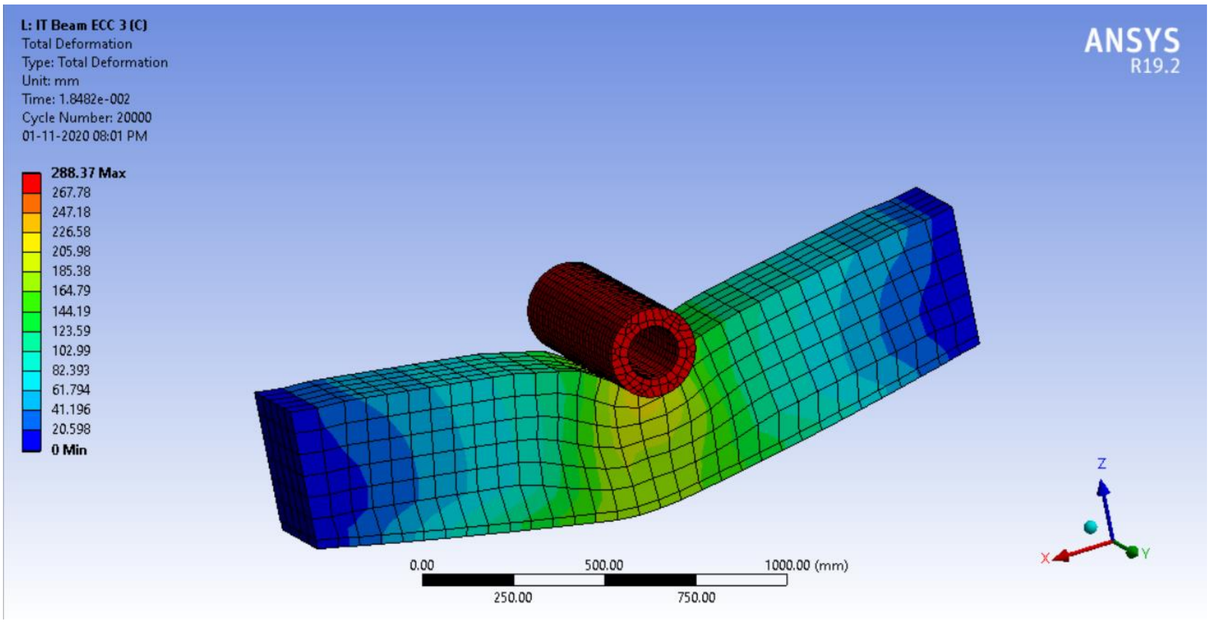
ECC 3 (B)

Deflection



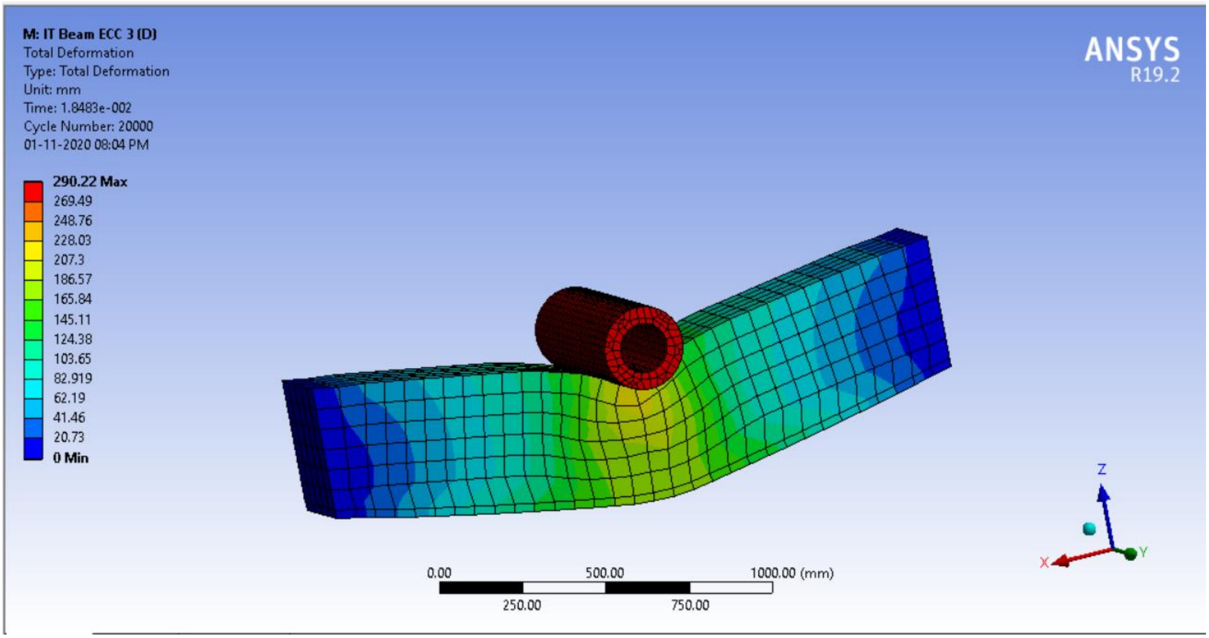
ECC 3 (C)

Deflection



ECC 3 (D)

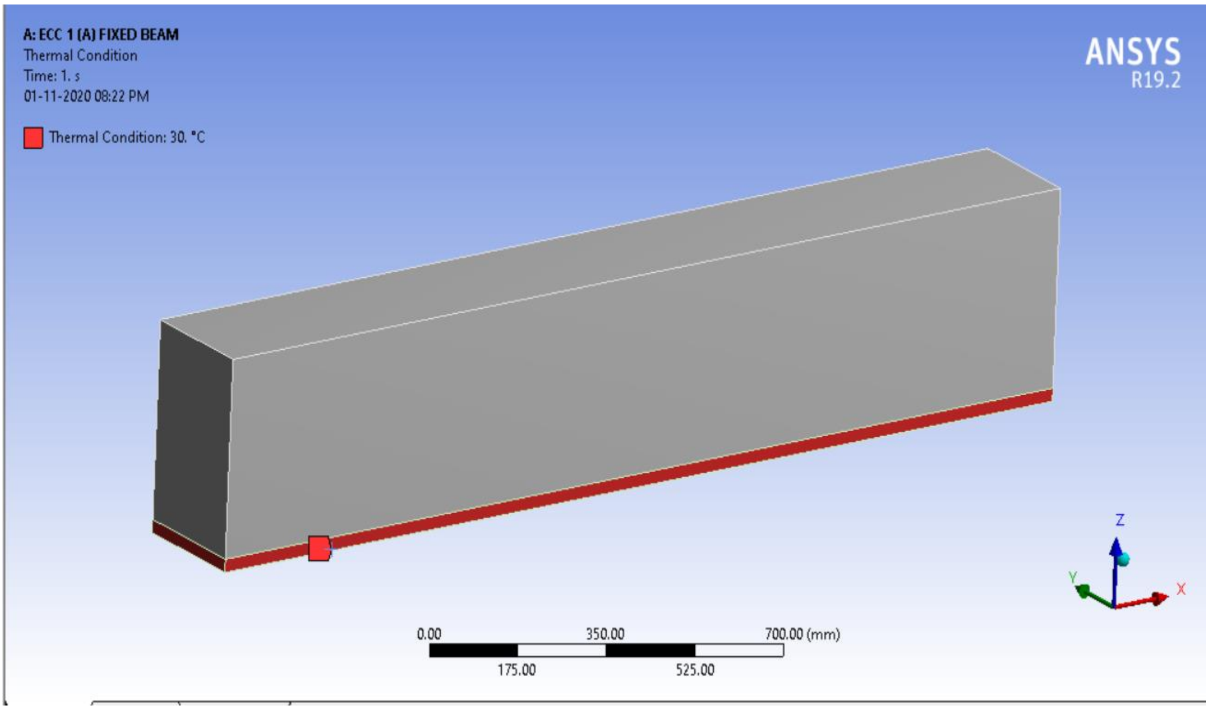
Deflection



7.3 Elevated Temperature Performance Analysis of ECC composites using ANSYS

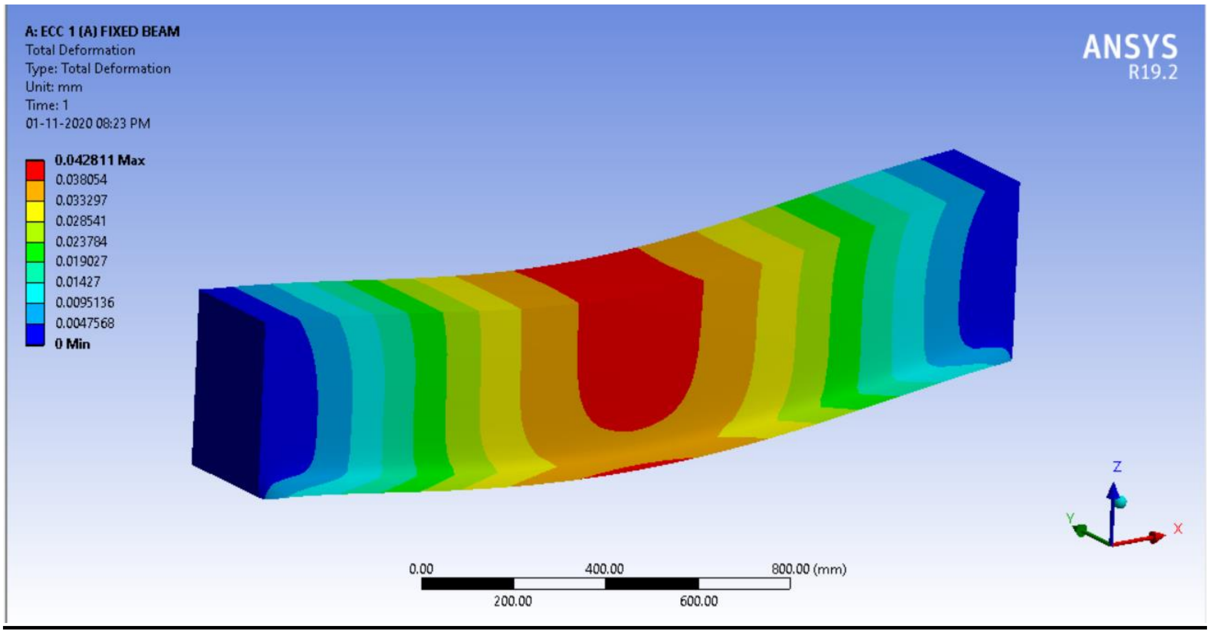
In this analysis ECC layered beams of ECC 1 material with 25mm, 30mm, 45mm and 60mm were analyzed at 30°C, 50°C, 70°C and 90°C.

The deflection in the beam are as:



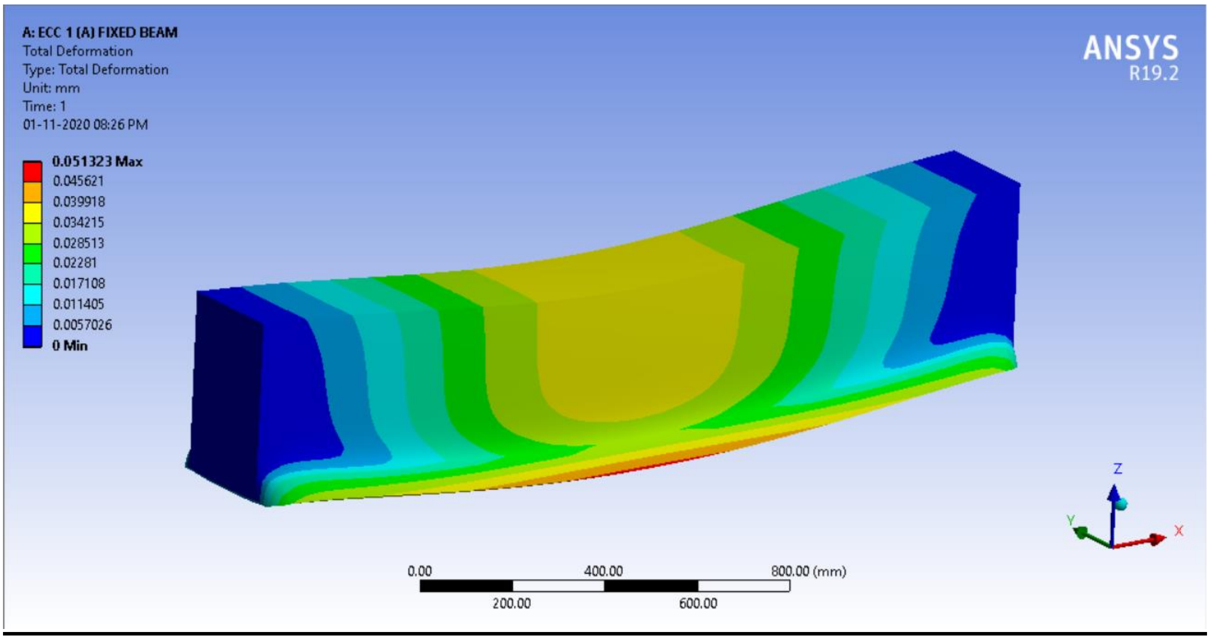
ECC 1 (A) @ 30°C

Deflection



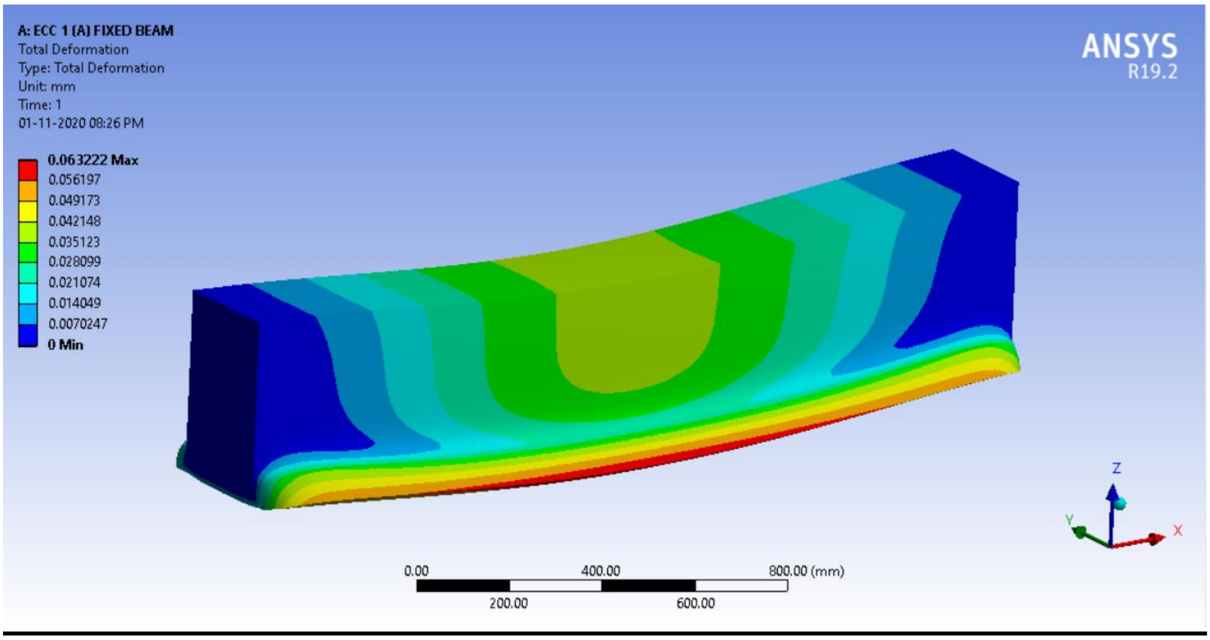
ECC 1 (A) @ 50°C

Deflection



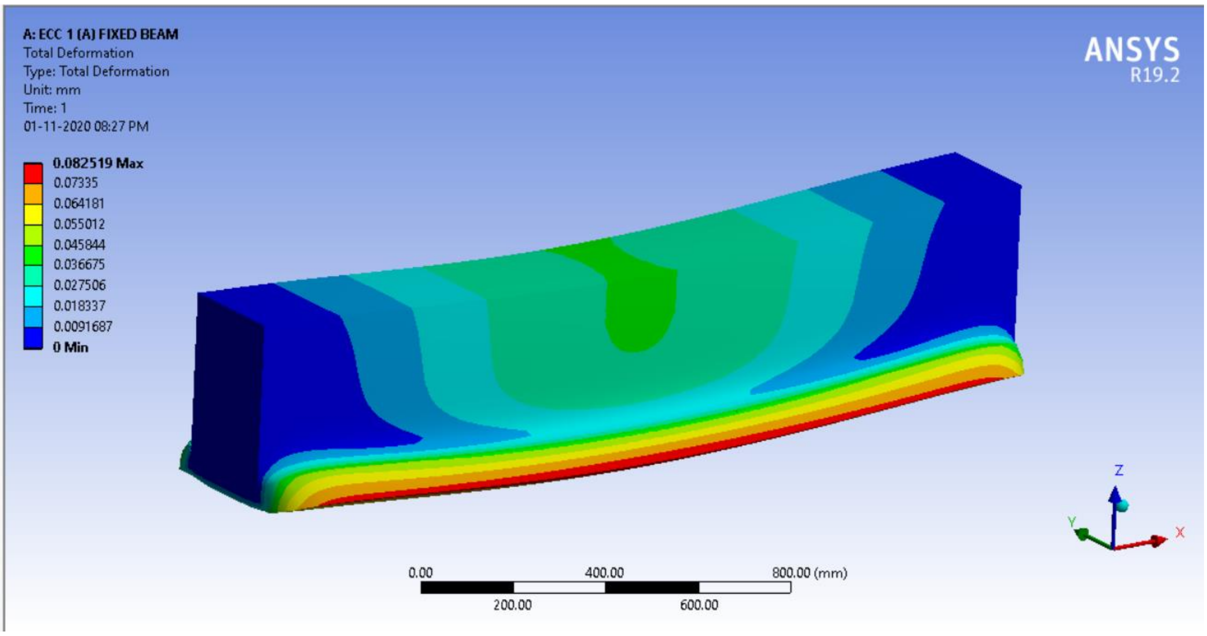
ECC 1 (A) @ 70°C

Deflection



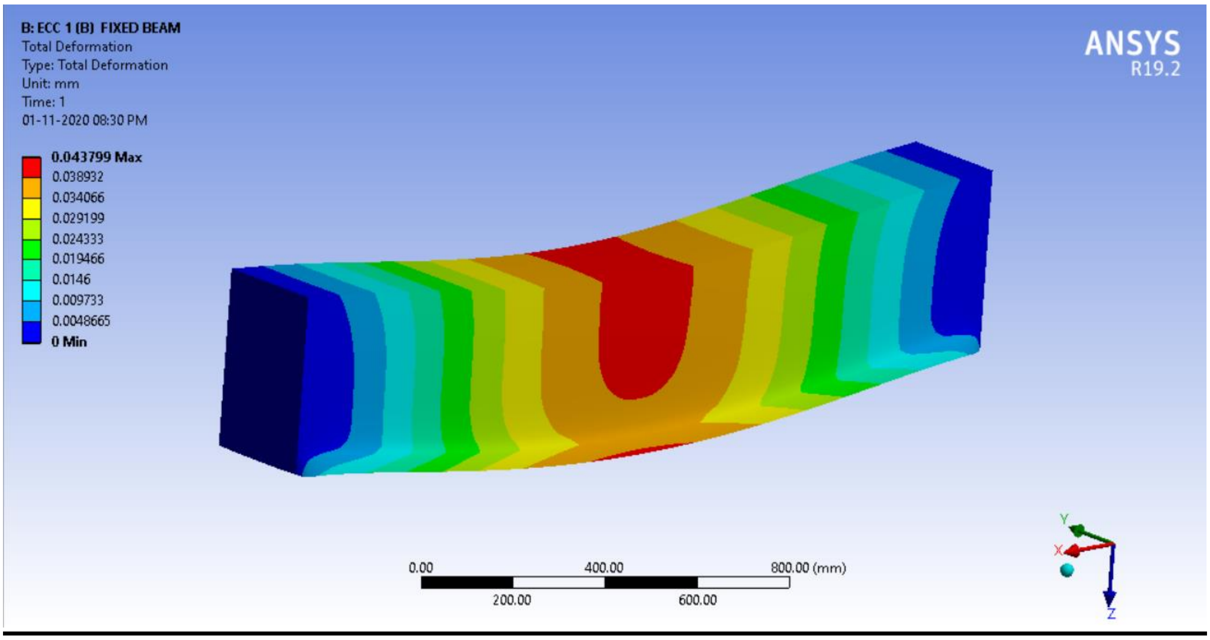
ECC 1 (A) @ 90°C

Deflection



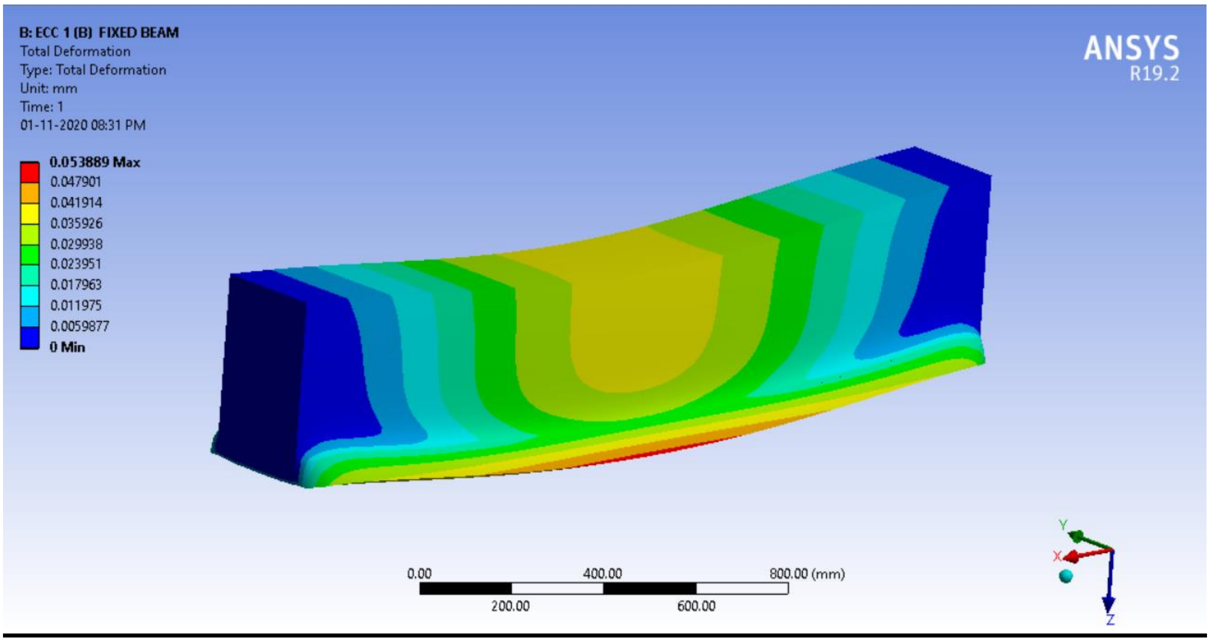
ECC 1 (B) @ 30°C

Deflection



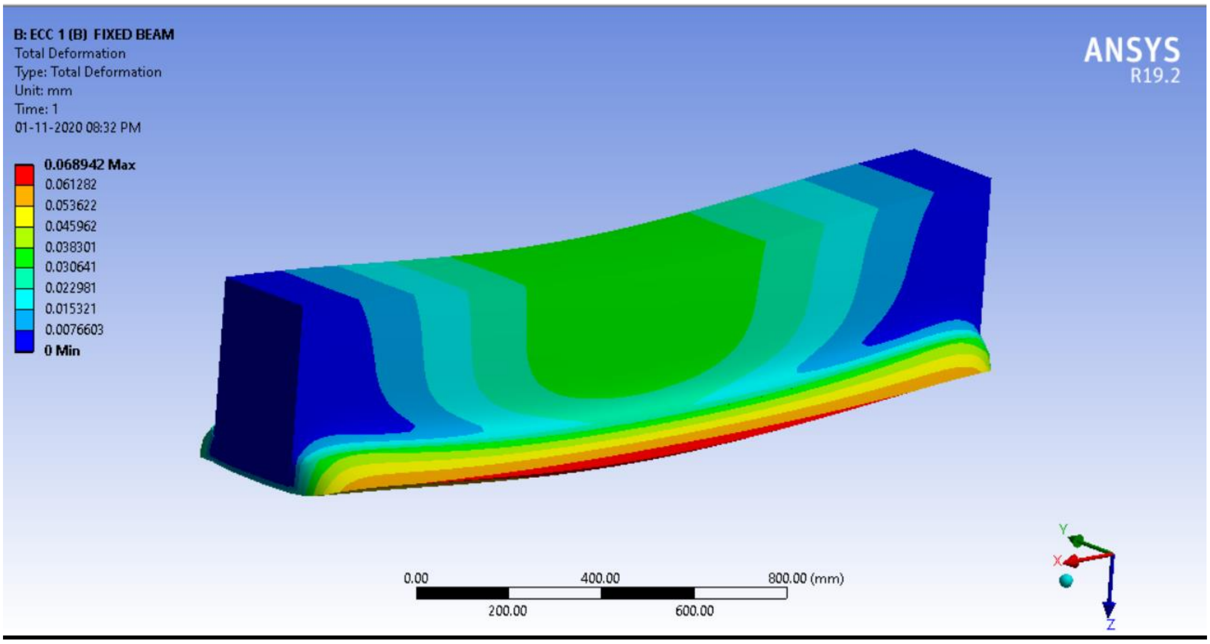
ECC 1 (B) @ 50°C

Deflection



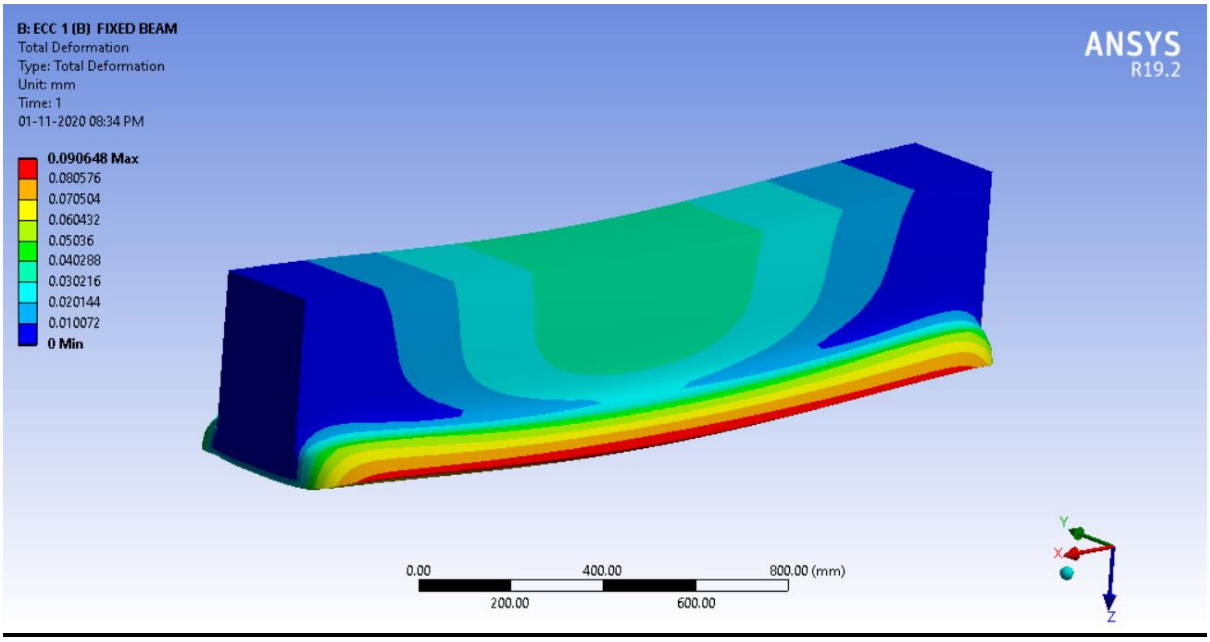
ECC 1 (B) @ 70°C

Deflection



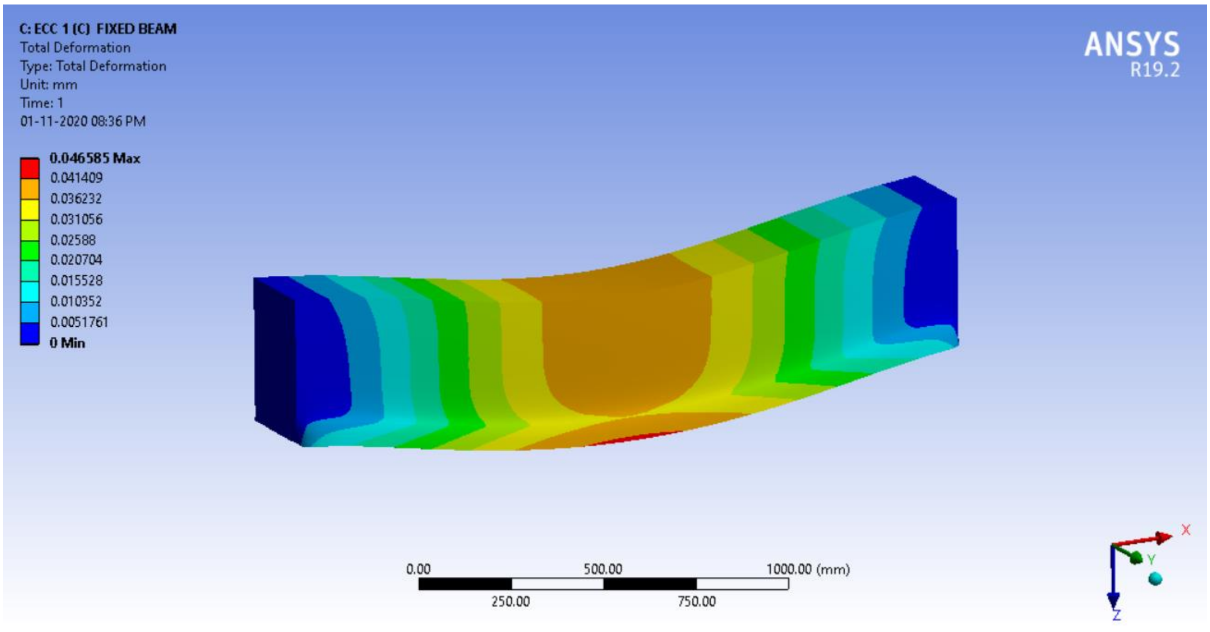
ECC 1 (B) @ 90°C

Deflection



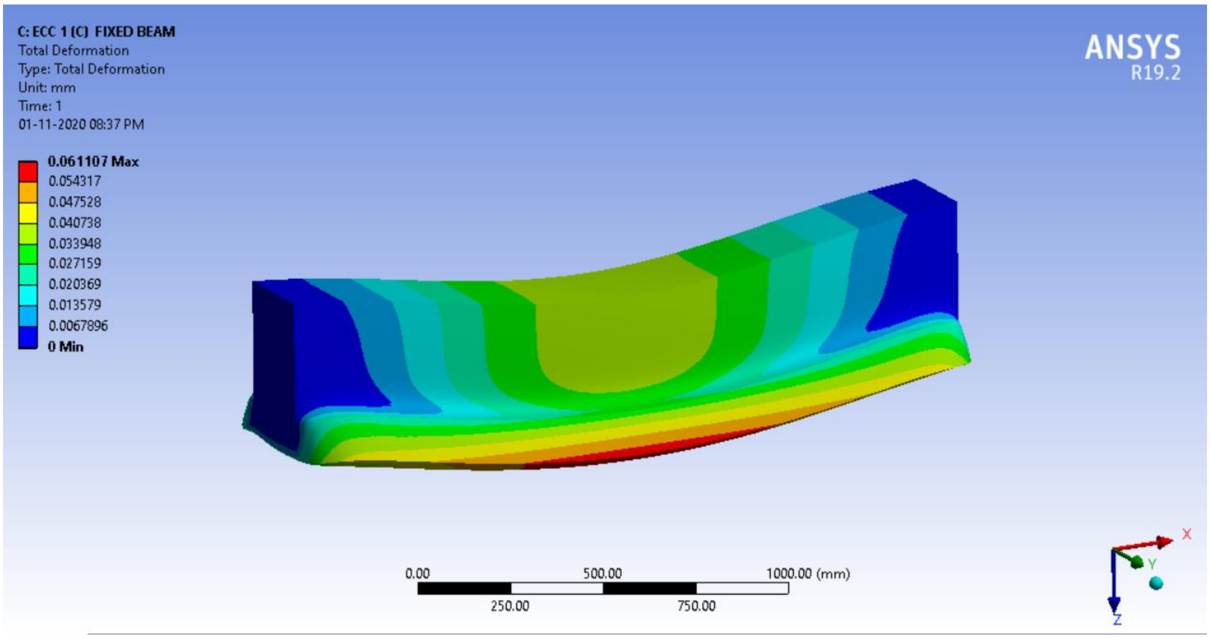
ECC 1 (C) @ 30°C

Deflection



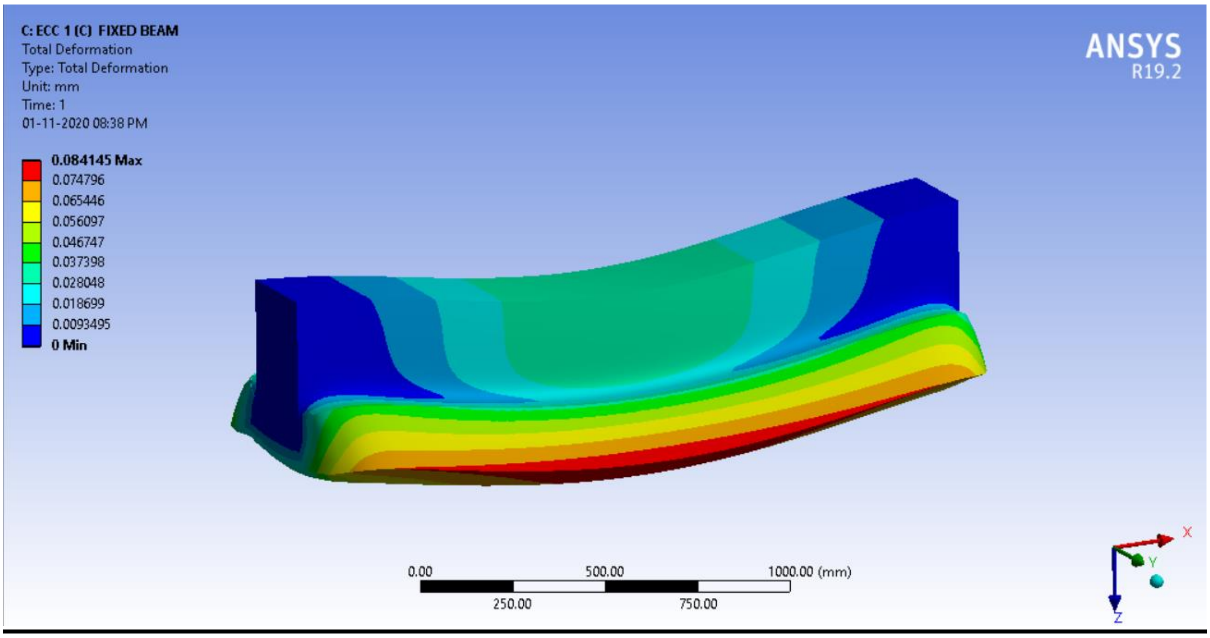
ECC 1 (C) @ 50°C

Deflection



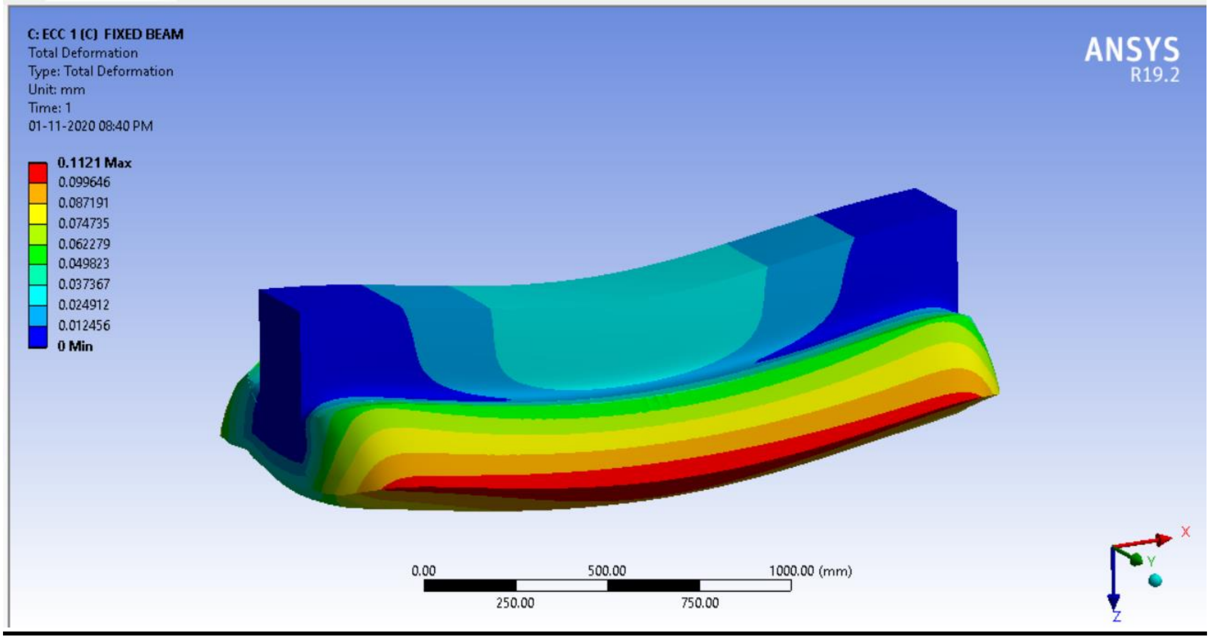
ECC 1 (C) @ 70°C

Deflection



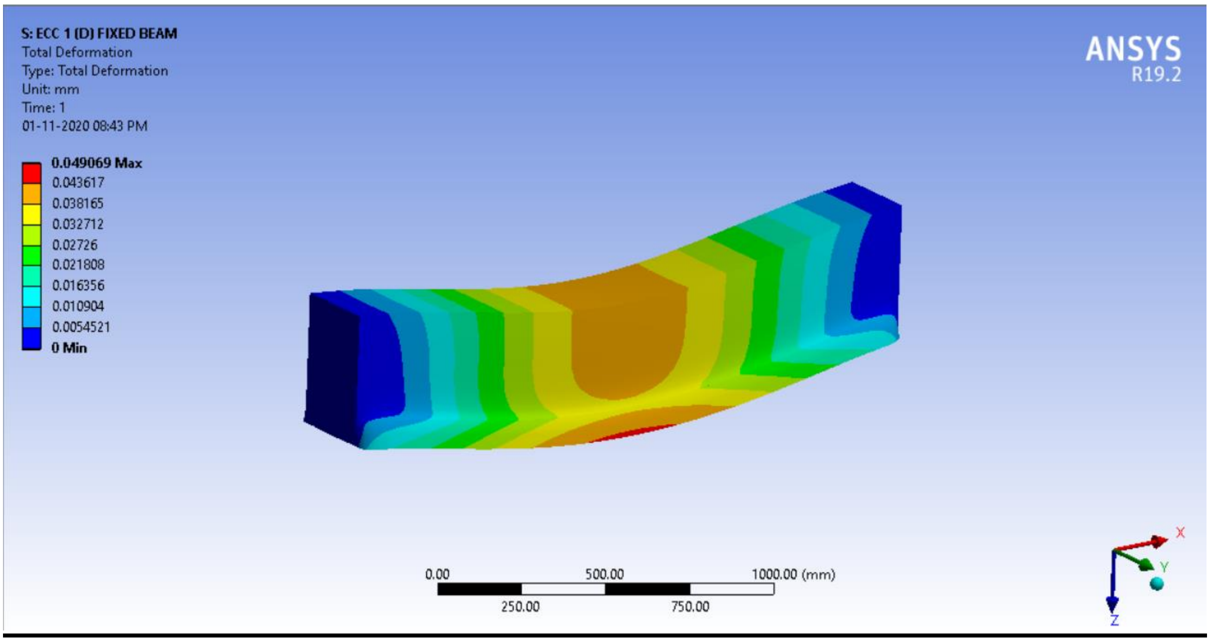
ECC 1 (C) @ 90°C

Deflection



ECC 1 (D) @ 30°C

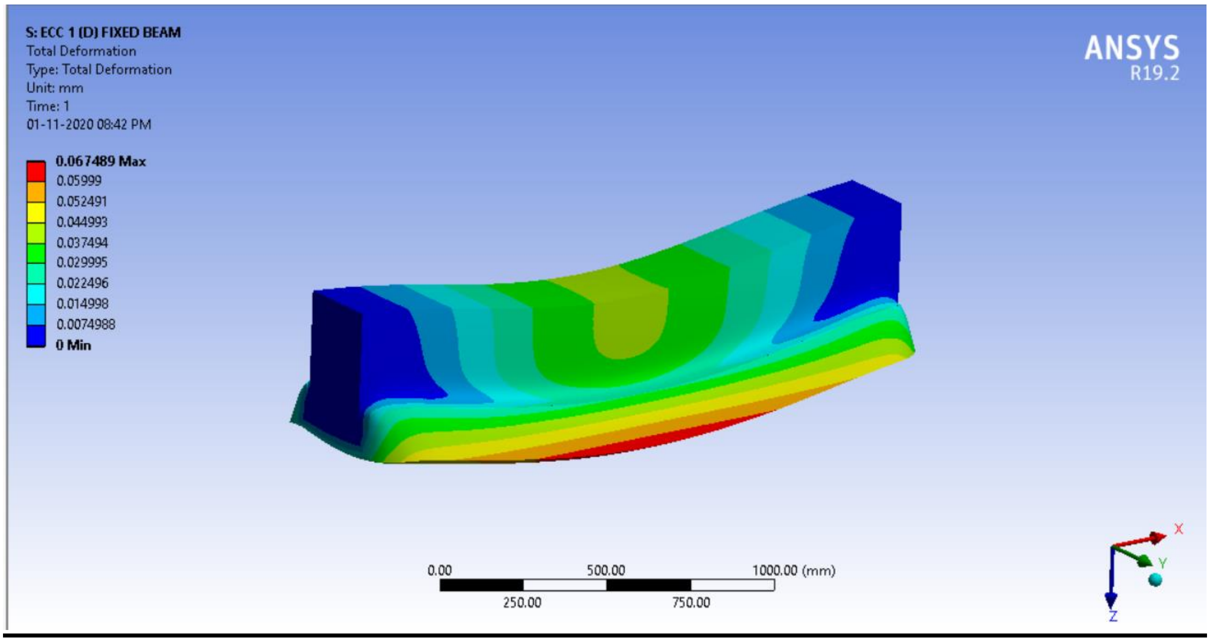
Deflection



S: ECC 1 (D) FIXED BEAM
Total Deformation
Type: Total Deformation
Unit: mm
Time: 1
01-11-2020 08:43 PM

ECC 1 (D) @ 50°C

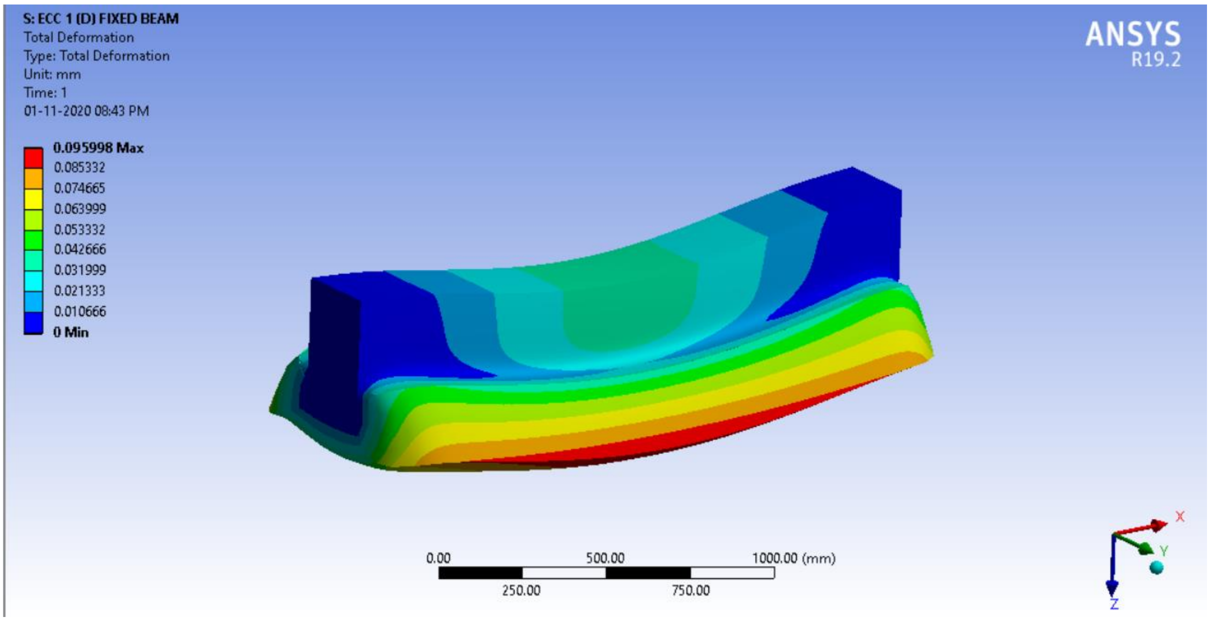
Deflection



S: ECC 1 (D) FIXED BEAM
Total Deformation
Type: Total Deformation
Unit: mm
Time: 1
01-11-2020 08:42 PM

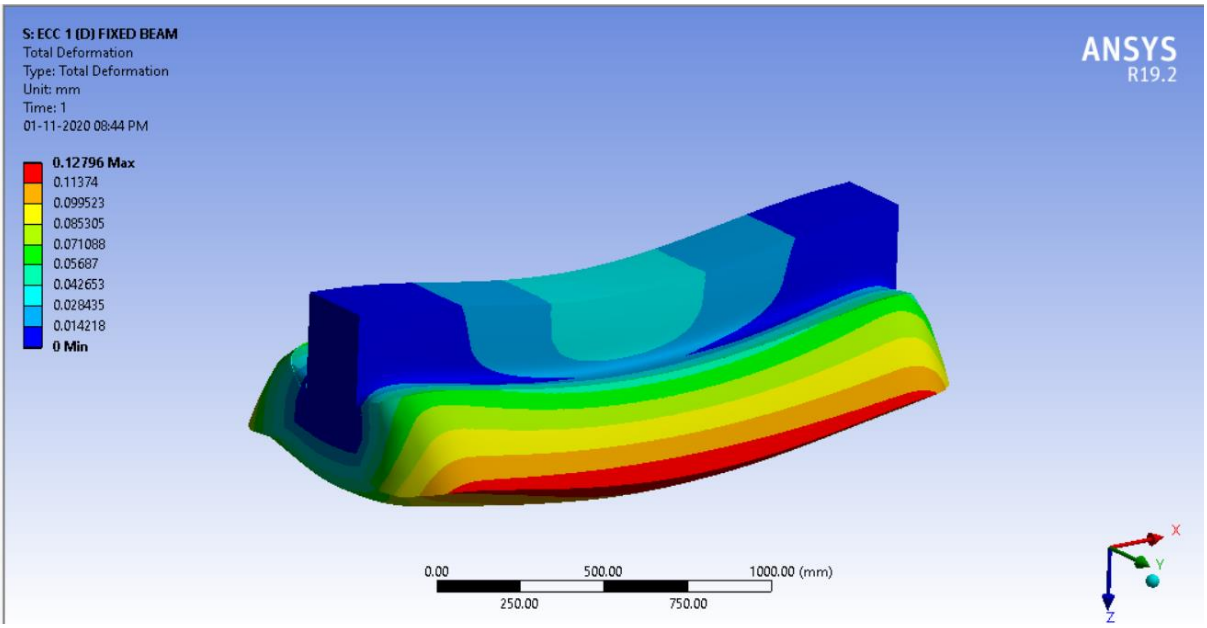
ECC 1 (D) @ 70°C

Deflection



ECC 1 (D) @ 90°C

Deflection



8.1 OBSERVATIONS

8.1.1 Total Deflection in the beams after the analysis (Fixed Beam)

Specimen No.	Total Deflection (mm)
ECC 1 (A)	0.040285
ECC 1 (B)	0.040642
ECC 1 (C)	0.041658
ECC 1 (D)	0.042587
ECC 2 (A)	0.040243
ECC 2 (B)	0.040592
ECC 2 (C)	0.041582
ECC 2 (D)	0.042487
ECC 3 (A)	0.040265
ECC 3 (B)	0.040587
ECC 3 (C)	0.041575
ECC 3 (D)	0.042478
Concrete beam	0.038236

8.1.2 Total Deflection in the beams after the analysis (Simply Supported Beam)

Specimen No.	Total Deflection (mm)
ECC 1 (A)	0.072026
ECC 1 (B)	0.072737
ECC 1 (C)	0.075086
ECC 1 (D)	0.076938
ECC 2 (A)	0.071945
ECC 2 (B)	0.072964
ECC 2 (C)	0.07495
ECC 2 (D)	0.07675
ECC 3 (A)	0.07187
ECC 3 (B)	0.072962
ECC 3 (C)	0.074941
ECC 3 (D)	0.076746
Concrete beam	0.068365

8.1.3 Deflection vs Stress

Specimen No.	**Total Deflection (mm)**		**Stress (extreme fibre) (MPa)**	
	Fixed Beam	**Simply supported beam**	**Fixed Beam**	**Simply supported beam**
ECC 1 (A)	0.040285	0.072026	2.2243	3.0312
ECC 1 (B)	0.040642	0.072737	2.2397	3.0527
ECC 1 (C)	0.041658	0.075086	2.2842	3.1992
ECC 1 (D)	0.042587	0.076938	2.2951	3.2191
ECC 2 (A)	0.040243	0.071945	2.2227	3.0289
ECC 2 (B)	0.040592	0.072964	2.2378	3.1319
ECC 2 (C)	0.041582	0.07495	2.2814	3.1953
ECC 2 (D)	0.042487	0.07675	2.2917	3.2141
ECC 3 (A)	0.040265	0.071817	2.2279	3.1161
ECC 3 (B)	0.040587	0.072962	2.2373	3.1313
ECC 3 (C)	0.041575	0.074941	2.2808	3.1945
ECC 3 (D)	0.042478	0.076746	2.2909	3.2133
Concrete Beam	0.038236	0.068365		

8.1.4 Deflection under Impact Loading

Specimen No.	**Total Deflection (mm)**
ECC 1 (A)	277.38
ECC 1 (B)	286.81
ECC 1 (C)	288.38
ECC 1 (D)	290.36
ECC 2 (A)	277.40
ECC 2 (B)	286.63
ECC 2 (C)	288.48
ECC 2 (D)	290.52
ECC 3 (A)	277.30
ECC 3 (B)	286.67
ECC 3 (C)	288.37
ECC 3 (D)	290.22
Concrete Beam	277.25

8.1.5 Deflection under Elevated Temperature

	Deflection (mm)			
Temperature	**30°C**	**50°C**	**70°C**	**90°C**
ECC 1 (A) 25 mm	0.042811	0.051323	0.063222	0.082519
ECC 1 (B) 30 mm	0.043799	0.053889	0.068942	0.090648
ECC 1 (C) 45 mm	0.046585	0.061107	0.084145	0.1121
ECC 1 (D) 60 mm	0.049069	0.086748	0.095998	0.12796

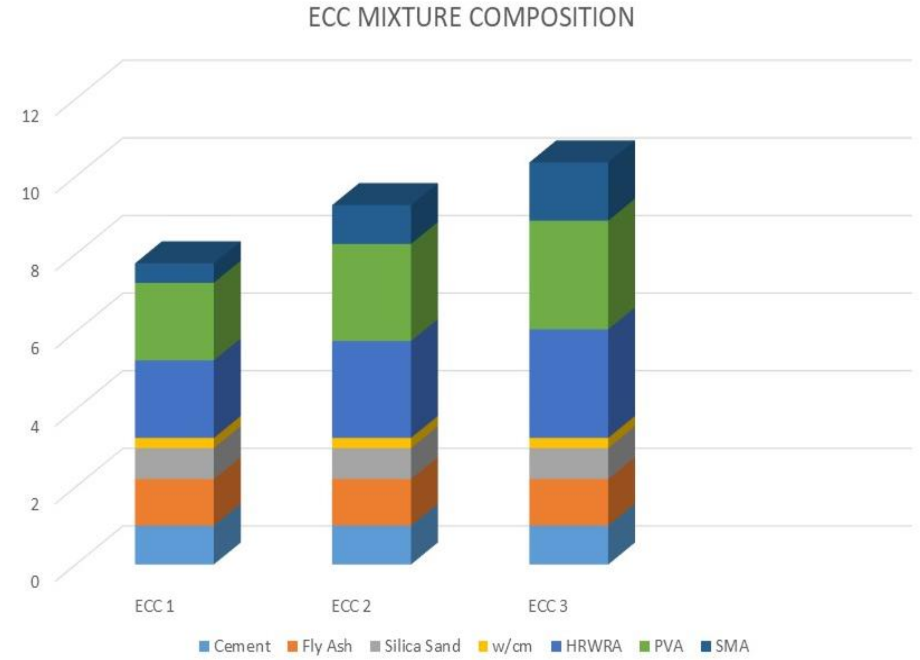
Deflection Check for Beams as per IS 456:2000:

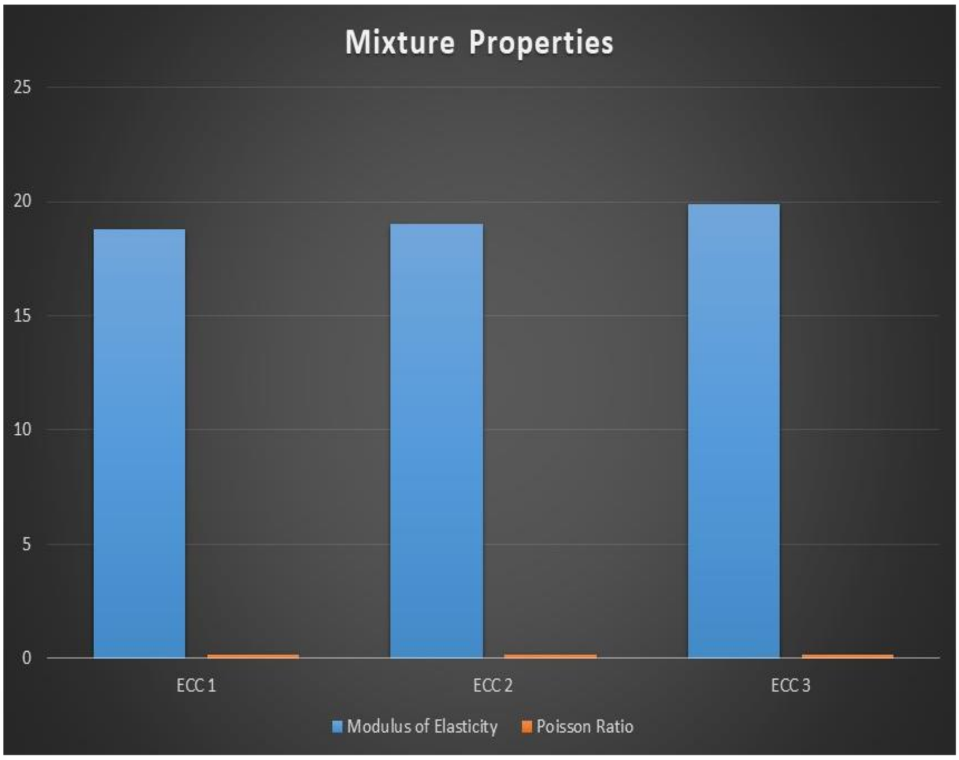
Indian standard code of practice has specified various span to depth ratio for calculation of deflection in clause - 23.2 which is simplified approximate method. In depth studies can be found in Annexure-C of IS 456:2000 which takes into account the value of long term creep also. The simplified procedure is based on experimental results as well as analytical method. So it may be termed as semi empirical procedure of deflection calculation.

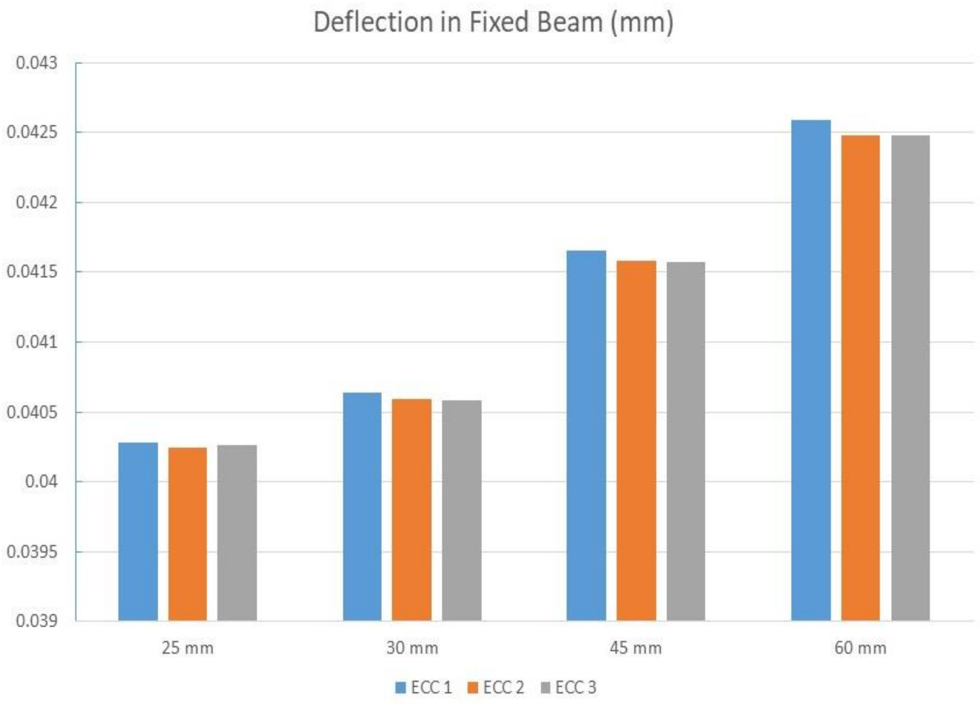
- The final deflection due to all possible type of loading due to creep, shrinkage and temperature effect etc. should not be greater than span/250 which is measured from as last level of supports of roofs.
- The deflection including effect of temperature, creep and shrinkage occurring after erection of partitions and the application of finishes should be restricted to span/350 or 20 mm whichever is lesser.
- The span to depth ratio should be limited to the following values in case of span up to 10m.

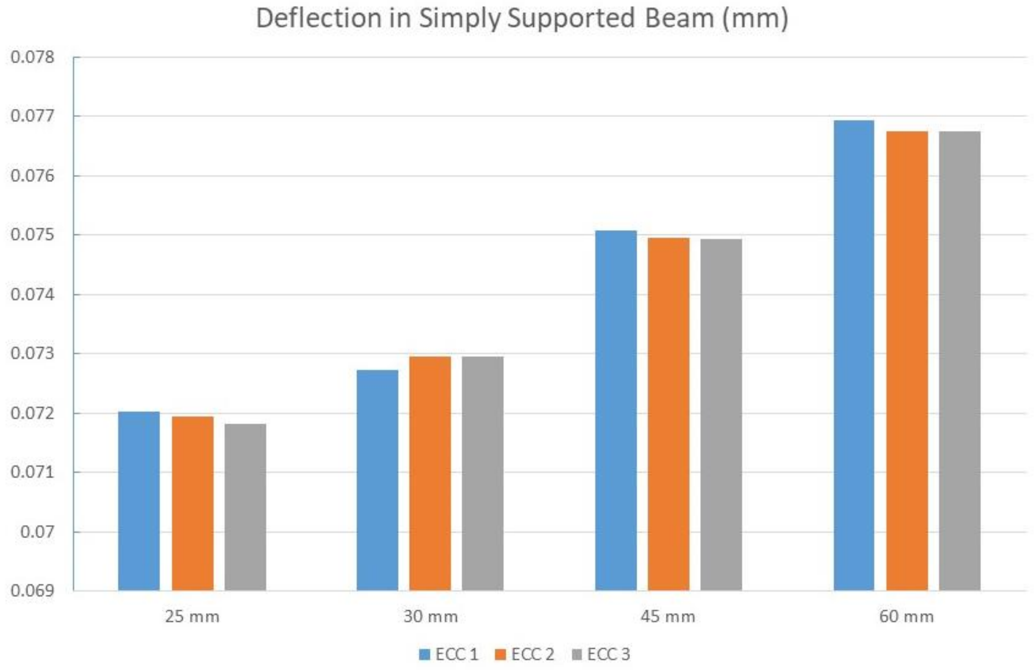
* Cantilever	7
* Simply supported	20
* Continuous	26

- If the span length exceeds 10m, then the above values should be multiplied to 10/span in case of absence of detailed analysis except for cantilever section; for which detailed analysis is mandatory.

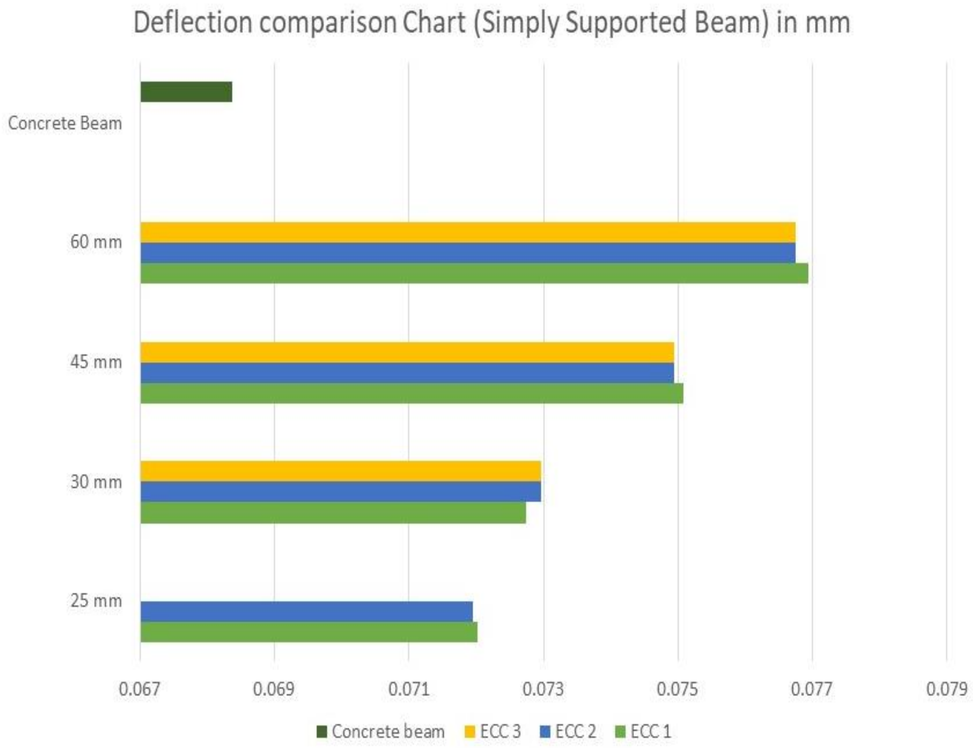

ECC MIXTURE COMPOSITION
0
2
4
6
8
10
12
ECC 1
ECC 2
ECC 3
Cement
Fly Ash
Silica Sand
w/cm
HRWRA
PVA
SMA

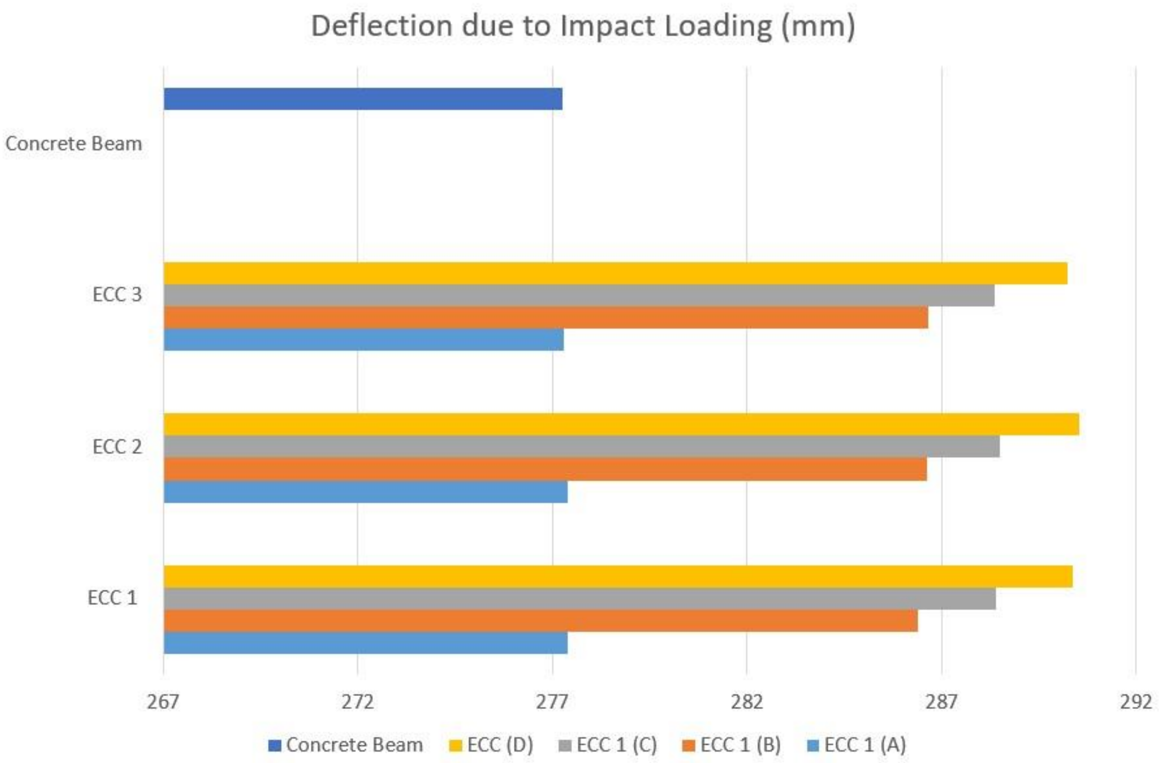

Mixture Properties
0
5
10
15
20
25
ECC 1
ECC 2
ECC 3
Modulus of Elasticity
Poisson Ratio

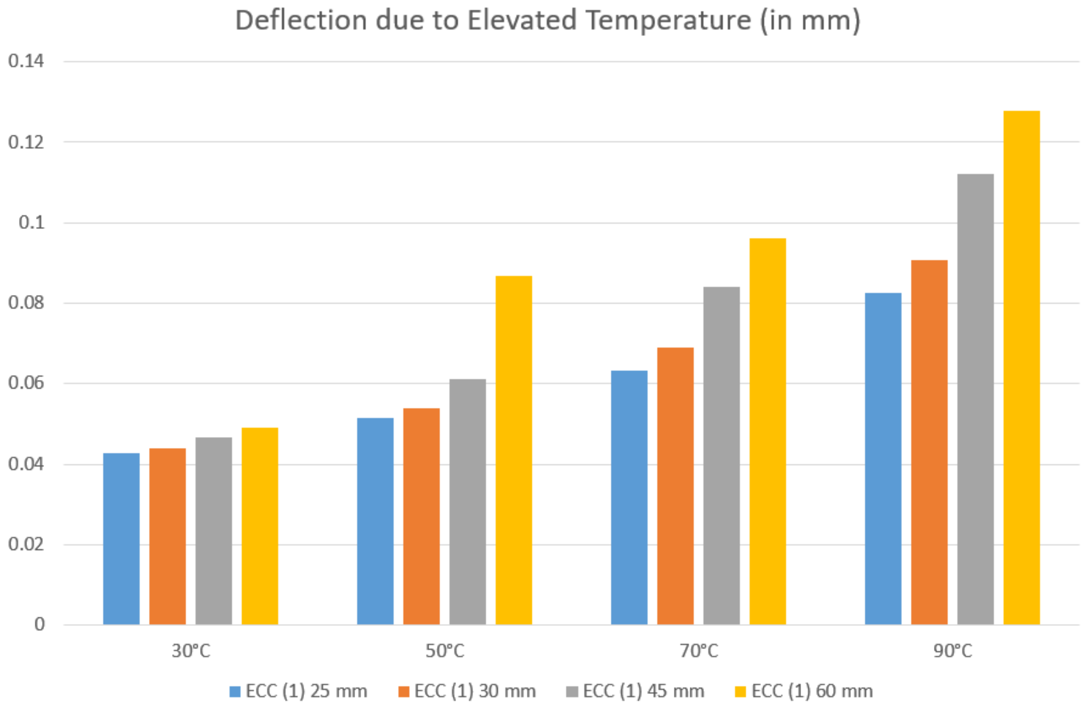

Deflection in Fixed Beam (mm)
0.043
0.0425
0.042
0.0415
0.041
0.0405
0.04
0.0395
0.039
25 mm
30 mm
45 mm
60 mm
ECC 1
ECC 2
ECC 3


Deflection in Simply Supported Beam (mm)
0.078
0.077
0.076
0.075
0.074
0.073
0.072
0.071
0.07
0.069
25 mm
30 mm
45 mm
60 mm
ECC 1
ECC 2
ECC 3


Deflection comparison Chart (Fixed Beam) in mm
Concrete beam
60 mm
45 mm
30 mm
25 mm
0.037
0.038
0.039
0.04
0.041
0.042
0.043
Concrete beam
ECC 3
ECC 2
ECC 1


Deflection comparison Chart (Simply Supported Beam) in mm
Concrete Beam
60 mm
45 mm
30 mm
25 mm
0.067
0.069
0.071
0.073
0.075
0.077
0.079
Concrete beam
ECC 3
ECC 2
ECC 1


Deflection due to Impact Loading (mm)
Concrete Beam
ECC 3
ECC 2
ECC 1
267
272
277
282
287
292
Concrete Beam
ECC (D)
ECC 1 (C)
ECC 1 (B)
ECC 1 (A)


Deflection due to Elevated Temperature (in mm)
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
30°C
50°C
70°C
90°C
ECC (1) 25 mm
ECC (1) 30 mm
ECC (1) 45 mm
ECC (1) 60 mm

8.2 RESULTS

From the observations I have found that:

- The deflection in the beams is within the permissible limits.
- The ECC composite beams can withstand the loading conditions in tension zone.
- ECC beam of material ECC 2, ECC 3 shows less deflection as compared to other material conditions.
- Material ECC 1 is much favourable to meet the deflection conditions.
- Using the different layers of ECC does effects the deflection of the beam.
- In Specimen 3 we have found that the deflection is less by increasing the thickness of the ECC material.
- The deflection is much higher in simply supported beam conditions.
- The optimum thickness of ECC Layer in the beam is 60 mm (20 percent of the depth) with M35 grade of concrete.
- Mixture Composition of ECC 1, ECC 2 and ECC 3 was used to for impact loading, ECC layer of 60 mm thickness shows much deflection under impact loading.
- Mixture Composition ECC 1 had some better results so it was also used for Elevated temperature conditions, the deflection in the beam changed by changing the layer thickness but the deflection also changed drastically upon increment in the temperature.

CHAPTER-9 CONCLUSION

In this study from the obtained results the beams satisfy the criteria of deflection as per IS 456:2000. ECC layer in the beams shows much favourable and withstanding conditions in the tension zone by meeting all the required conditions. 3 types of material mixtures were used for the analysis, materials were same but only their percentage of PVA and SMA fibres were changed.

It was also found out Specimen ECC 1 with 2% PVA fibres and 0.5% SMA show much favourable deflection criteria. By changing the thickness of the layers we can see the changes in the properties of the beams.

Specimen ECC 3 shows less deflection as it has 1.5% of SMA due to its property 869 MPa (Ultimate tensile strength) and 41 GPA (Modulus of elasticity.) The more the value of young's modulus, more force is required to deform it. On comparing the results of fixed beam and Simply Supported beams the deflection is greater in simply supported beams as compared to fixed beams. Simply supported beams of ECC can deflect much other than fixed beams.

By using initial layer of 25 mm thickness and then gradually increasing the layer thickness by 10 %, 15 % and 20 % the layer thickness of 60 mm is the optimum layer thickness which is 20 % the depth of the beam.
Under impact loading condition the deflection in the beam is much more in the case of 60 mm layered thickness beam of all the mixtures, that shows under impact loading ECC beams & performance can also be enhanced by changing the layer thickness in the tension zone more than 60 mm.

Elevated temperature analysis was also performed by using the ECC 1 mixture at 4 temperatures 30, 50, 70, 90 degree Celsius, the deflection in the beam increased by increasing the layer thickness. The deflection changed drastically at 90°C with 60 mm thickness. So, ECC layered beam of greater thickness can't perform well in the high temperature conditions.

CHAPTER-10 REFRENCES

[1]. Application of Engineered Cementitious Composites (ECC) in interior beam–column connections for enhanced seismic resistance. S. Qudah, M. Maalej / Engineering Structures 69 (2014) 235–245 Elsevier Publications.

[2]. Structural Behavior of Reinforced Self-Compacted Engineered Cementitious Composite Beams. Bashar S. Mohammed et al Hindawi Publishing Corporation Advances in Materials Science and Engineering Volume 2016, Article ID 5615124, 12 pages.

[3]. Flexural performance of concrete beams containing engineered cementitious composites. A.S. Shanour et al. / Construction and Building Materials 180 (2018) 23–34 Elsevier Publications.

[4]. Study of modulus of elasticity of RC beam under flexural loading using ANSYS. International Journal Of scientific and engineering research, Volume 7, issue 3, March 2016, ISSN 2229-5518.

[5]. Studies on flexural behaviour of PVA reinforced bendable concrete composite- Dr M RameGowda, Ms Uma Devi, Somashekar.N, Rithinkumar M.B,-ICJ,June 2014,vol 88,no 6.pp 25-32

[6]. Engineered Cementitious Composites for Structural Applications –Dr. A. W. Dhawale, Mrs. V. P. Joshi. Volume 2, Issue 4, April 2013,ISSN 2319 – 4847.

[7]. A Literature Review on Engineered Cementitious Composites for Structural applications- Srinivasa. C. H. et al International Journal of Engineering Research & Technology (IJERT) ISSN: 2278-0181 IJERTV3IS120448 www.ijert.org Vol. 3 Issue12, December-2014.

[8]. Engineered cementitious composites (ECC) – material, structural, and durability performance – Victor c. Li , Concrete Construction Engineering Handbook, Chapter 24, Ed. E. Nawy, published by CRC Press, 2008.

[9]. Engineered cementitious composites with high-volume fly ash Shuxin wang and Victor c. Li.ACI Materials Journal, V. 104, No. 3, May-June 2007.

[10]. Use of High Volumes of Fly Ash to Improve ECC Mechanical Properties and Material Greenness -by EnHua Yang, Yingzi Yang, and Victor C. Li, ACI Materials Journal, V. 104, No. 6, November-December 2007.

[11]. En-Hua Yang et.al. (2008) “Fiber-bridging constitutive law of engineered cementitious composites,” Journal of advanced concrete technology Vol. 6, No. 1, pp.181-193.

[12]. Mustafa Sahmaran et.al (2008), “Corrosion Resistance Performance of Steel _reinforced Engineered Cementitious composite Beams.” ACI Materials Journal / May-June 2008, pp 243-250.

[13]. Mustafa Sahmaran et.al. (2009), “Assessing the durability of engineered cementitious composites under freezing and thawing cycles,” Journal of ASTM International, Vol. 6, No. 7, Paper ID JAI102406. pp. 1-12.

[14]. Victor C. Li. and winter (2011) University of Michigan. “High ductility concrete for resilient infrastructures,” Journal of advanced and high performance materials, pp.16-21.

[15]. Mo Li and Victor C Li (2011), “ High-Early-Strength Engineered Cementitious Composites for fast, durable Concrete Repair-Material Properties.”, ACI Material Journal/January-February 2011, pp 3-12.

[16]. Dr. A. W. Dhawale and Mrs. V. P. Joshi., “Engineered Cementitious Composites for Structural Applications.” International journal of application or innovation in Engineering and Management., Volume 2, Issue 4, April 2013., pp 198-205.

[17]. Alberti M G, Enfedaque A, Galvez J C, Canovas M F and Osorio I R (2014), “Polyolefin fibrereinforced concrete enhanced with steel-hooked fibres in low proportions”, Journal of Materials and Design, Vol. 60, pp. 57–65.

[18]. Bensaid Boulekbache, Mostefa Hamrat, Mohamed Chemrouk and Sofiane Amziane (2012), “Influence of yield stress and compressive strength on direct shear behaviour of steel fibrereinforced concrete”, Journal of Construction and Building Materials, Vol. 27, pp. 6–14.

[19]. Jian Zhou, Shunzhi Qian, Guang Ye, Oguzhan Copuroglu, Klaas van Breugeland Victor C Li (2012), “Improved fibre distribution and mechanical properties of engineered cementitious composites by adjusting the mixing sequence”, Journal of Cement & Concrete Composites, Vol. 34, pp. 342–348.

[20]. Jun Zhang, Zhenbo Wang and Xiancun Ju (2013), “Application of ductile fibre reinforced cementitious composite in joint less concrete pavements”, journal of Composites, Part B, Vol. 50, pp. 224– 231.

[21]. Mustafa Sahmaran, Zafer Bilici, Erdogan Ozbay, Tahir K. Erdem, Hasan E Yucel and Mohamed Lachemi (2013), “Improving the workability and rheological properties

of Engineered Cementitious Composites using factorial experimental design", Journal of Composites: Part B, Vol. 45, pp. 356-368.

[22]. Pajak M and Ponikiewski T (2013), "Flexural behaviour of self-compacting concrete reinforced with different types of steel fibres", Journal of Construction and Building Materials, Vol. 47, pp. 397- 408.

[23]. Qian S Z, Zhou J and Schlangen E (2010), "Influence of curing condition and precracking time on the self-healing behaviour of Engineered Cementitious Composites", Journal of Cement & Concrete Composites, Vol. 32, pp. 686– 693.

[24]. Soutsos M T, Le T T and Lampropoulos A P (2012), "Flexural performance of fibre reinforced concrete made with steel and synthetic fibres", Journal of Construction and Building Materials, Vol. 36, pp. 704- 710.

[25]. Tahir Kemal Erdem (2014), "Specimen size effect on the residual properties of engineered cementitious composites subjected to high temperatures", Journal of Cement & Concrete Composites, Vol. 45, pp. 1–8.

[26]. Yu Zhu, Yingzi Yang and Yan Yao (2012), "Use of slag to improve mechanical properties of engineered cementitious composites (ECCs) with high volumes of fly ash", Journal of Construction and Building Materials, Vol. 36, pp. 1076- 1081.

[27]. Yu Zhu, Zhaocai Zhang, Yingzi Yang and Yan Yao (2014), "Measurement and correlation of ductility and compressive strength for engineered cementitious composites (ECC) produced by binary and ternary systems of binder materials: Fly ash, slag, silica fume and cement", Journal of Construction and Building Materials, Vol. 68, pp. 192-198.

[28]. https://en.wikipedia.org › wiki › Engineered_cementitious_composite.

TABLE OF CONTENTS

Contents **Page No.**

Title Page ....(i)

Declaration.. (ii)

Certificate.. (iii)

Acknowledgment ....(iv)

List of Tables ....(v)

List of Abbreviations .... (vi)

Chapter-1 Introduction **01-03**

Chapter-2 Objectives **04**

Chapter-3 Literature Review **05-15**

Chapter-4 Literature Summary **16**

Chapter-5 Research Gap **17**

Chapter-6 Methodology **18-23**

6.1 Using Ansys Software…………………………………………18-19
    6.1.1 Modelling in Ansys…………………………………..19
    6.1.2 Meshing in Ansys…………………………………….19
6.2 Data Used…………………………………………………….20
    6.2.1 Beam Design Data……………………………………20-21
6.3 Properties of Materials…………………………………………22-23

Chapter-7 Analysis **24-65**

7.1 Deflection Analysis of ECC composites using ANSYS………….24-49
7.2 Impact Loading Performance Analysis of ECC
    composites using ANSYS………………………………………50-56
7.3 Elevated Temperature Performance Analysis of
    ECC composites using ANSYS…………………………………57-65

Chapter-8 Observations and Results **66-73**

8.1 Observations…………………………………………….…………….66
- 8.1.1 Total Deflection in the beams after the analysis (Fixed Beam)……………….…………….66
- 8.1.2 Total Deflection in the beams after the analysis (Fixed Beam)……………….…………….66
- 8.1.3 Deflection vs Stress……………………….………………67
- 8.1.4 Deflection under Impact Loading………..………………….67
- 8.1.5 Deflection under Elevated Temperature…….……………68

8.2 Results……………………………………………………………73

Chapter-9 Conclusion **74**

Chapter-10 References **75-77**