



e-ISSN: 2319-8753 | p-ISSN: 2320-6710

# IJRSET

International Journal of Innovative Research in  
**SCIENCE | ENGINEERING | TECHNOLOGY**

# INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH

IN SCIENCE | ENGINEERING | TECHNOLOGY

Volume 10, Issue 6, June 2021

**ISSN** INTERNATIONAL  
STANDARD  
SERIAL  
NUMBER  
INDIA

**Impact Factor: 7.512**

9940 572 462

6381 907 438

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# Analytical Behaviour of Slender Beams with Sustainable Variants of Concrete

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**ABSTRACT:** The earth's resources are at the verge of depletion. It is our responsibility to ensure minimal destruction to the ecological system. As an engineer, we must adopt shift from conventional to eco-friendly construction practices. The eco-friendly approach to prepare concrete has led to the innovation of sustainable variants of concrete like bacterial concrete (BC), fibre added recycled concrete (FARC), fly ash based geopolymer concrete (FGPC), recycled fine and coarse aggregate concrete (RC), etc. The analysis of these variants of concrete is one of the many topics of interest for researchers. In this work, the flexural behaviour of a simply supported beam with the mentioned concrete properties modeled using a finite element software, ATENA is investigated to get the factual behaviour of these concrete types. The input data fed to the system the concrete properties which defines the beam were taken from various project reports proposed by other researchers. The breaking load, the loads at which cracks occurred in tension and compression zones, and stress and strain in these zones were determined to get a better understanding of these variants. The superior quality concrete among these sustainable variants and the most suitable concrete among the analysed sustainable variants are also proposed in this work.

**KEYWORDS:** ATENA, Sustainability, Conventional concrete, Bacterial concrete, Fibre added recycled aggregate concrete, Fly ash based geopolymer concrete, Recycled fine and coarse aggregate.

## I. INTRODUCTION

The resources that decorated the environment is depleting day by day. Hence it is essential to adopt sustainable ways of construction. The production of ordinary Portland cement emits a large amount of CO<sub>2</sub> into the atmosphere. Also from the structural aspects, concrete is good in compression but it is not versed in tension. Various methods have been incorporated to enhance the tensile character of concrete. The alternations to reduce the environmental impact and at the same time enhancing the properties of conventional concrete (CC) led to innovations like bacterial concrete, fibre added reinforced concrete, fly ash based geopolymer concrete, recycled aggregate concrete, etc.

The work aims at the comparative study of the real behavioural properties of concrete beams with different material properties. The usual approach employed is the experimental analysis which demands manpower and time. The experiments are done on a proportionate prototype. So there is a need for analysing beams analytically which helps in curtailing both the cost and time. In this work a 3D finite element software ATENA 3D v4 is employed to study the realistic behaviour of a variety of sustainable concrete whose basic hardened properties are known. The primary objective of the study points to the stimulation of the real behaviour of concrete structures. The software incorporates non-linear finite element analysis to provide reliable results.

## II. RELATED WORK

Since the advent of computers, human beings have relied on them as a way to find solutions for their problems. But many a time, we lack the accuracy and authenticity of the solutions. We are analysing the performance of sustainable variants of concrete using ATENA software. The accuracy and reliability of the software are investigated with the help of related works.

Validation of experimental results with the computational method was stated by Dia Eddin Nassani *et al.*[1]. He validated the accuracy of finite element analysis for the analysis of hybrid fibre concrete by using ANSYS software. The software ATENA 3D v4 employed finite element analysis, stiffness method, and Newton-Raphson method for the

analysis. Qiong Liu *et al.*[2] compared the strain at the same points with the finite element method and the traditional strain gauges. He thus ascertained the dependence on finite element analysis. The reliability of the software ATENA was already studied by Kannam *et al.* [3] by analysing the shear behaviour of steel fibrous self-compacting concrete on an experimental setup and using numerical models in ATENA.

One of the sustainable variants of concrete analysed was recycled fine and coarse aggregate concrete. Ravande Kishore [4] conducted a laboratory experiment on recycled aggregate concrete and conventional concrete and concluded with an inclination towards the usage of recycled materials as an alternative for natural aggregates. Researchers came up with the idea of fibre reinforced concrete to tackle the low tensile strength of concrete. M. Heeralal *et al.* [5] investigated the flexural fatigue behaviour of Steel Fibre Reinforced Recycled Aggregate Concrete (SFRRAC) and put forth the conclusion that the inclusion of fibres can benefit the fatigue performance of recycled aggregate concrete. Yasir Sofi *et al.* [6] intended to study the properties of fly ash based geopolymer concrete and concluded that it possesses good compressive strength and offer good durability characteristics. S S P Reddy *et al.* [7] obtained the performance of concrete by microbiologically induced special growth filter to heal the concrete crack. He observed a reduction in pore size thereby an improvement in the compressive strength and split tensile strength for the bacterial concrete.

The input data for the work include the compressive strength, split tensile strength, and modulus of elasticity. These input data were collected from the various experimental setup conducted by Anas M *et al.*[8], Savitha Jose *et al.*[9], Chinju Janavardhan O *et al.*[10], Abhijith Manoj *et al.*[11].The work is performed on a simply supported beam having two-point loading. Jan Červenka *et al.* [12] provided the tutorial for ATENA 3D v4 and the same simply supported beam as explained is employed in this work.

The viability of finite element analysis and the experimental outcomes on different variants of concrete is ensured from different literature.

### III. ANALYTICAL MODELLING

The analysis on sustainable variants of concrete was done with the software ATENA 3D v4 on a simply supported beam with four points loading. For comparison, it is necessary to maintain uniformity while modelling the beams. Hence the beam with the same dimension but with different material properties were analysed and studied. The software performs modelling and analysis in three steps, mainly, pre-processing, run, and post-processing.

#### Beam geometry

The beam model employed in the study was taken from Leonhard experimental setup in the year 1962. The beam is having a length of 2550 mm, breadth of 190 mm, and height of 320 mm as shown in figure 1. Since the beam is symmetrical, only half of the beam is analysed in this work (figure 2). The model consists of the concrete beam, steel supporting plate, loading plate, and two longitudinal reinforcement bars. Reinforcement bars are having a diameter of 26 mm and the total areas of the steel bars are 1060 mm<sup>2</sup>. The plates are used to avoid unrealistic stress concentration which may cause premature cracking at these locations. If the loads are applied at single point, it will cause high stress concentration at the point of application [12].

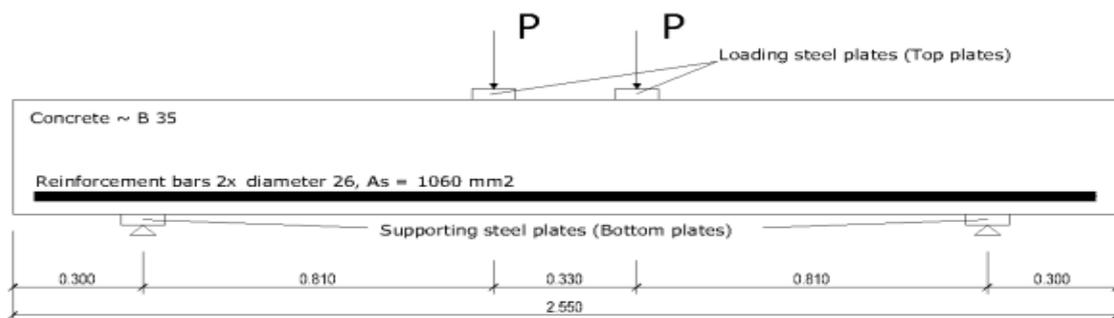


Figure 1: Geometry of structure

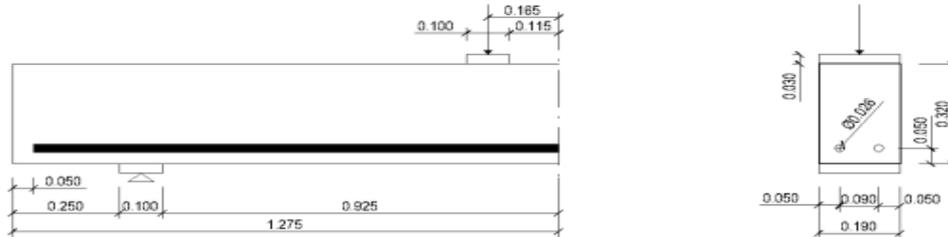


Figure 2: Cross-section of beam

### Pre-processing

The analytical model for the finite element analysis will be created during the pre-processing with the help of a fully automated mesh generator. The definition of the geometrical model starts with the addition of the global structural parameters and global solution parameters. The next step involves the definition of material groups and material properties. The beam used in analysis employs three materials which are elastic material for the steel plates at support and loading points, concrete for the beam, and reinforcement material. The method of direct definition is used in defining the materials over other methods like using data from previously saved material definition or selection from the catalogue.

The input properties required in the material type steel plates include elastic modulus and Poisson's ratio. Similarly, reinforcement requires elastic modulus and yield stress as the input data. The concrete for the beam can be specified by numerous parameters. The input data given include cube strength, modulus of elasticity, and split tensile strength. The given input data are collected from other works [8]-[11]. The parameters other than the ones fed to the software were generated based on the concrete cube strength. Once the definition of materials is over the next step is the generation of the beam. The analysed structure is symmetrical, hence only the symmetrical half is analysed. The beam is generated by specifying the global coordinates (figure 2) and the material for the beam is also assigned. Steel plates are provided at the loading and supporting region. Finite element non-linear analysis is often necessary to avoid any unrealistic stress concentration, as this may cause premature failure or crack in these locations [12]. If the loads are applied at a single point, it will build a strong stress concentration which will affect the result of the analysis. Hence steel plates are provided at the support point and loading point to make the analysis realistic.

The steel plates are generated by specifying the joint coordinates and defining the lines and surfaces. Hence a two-dimensional macro-element cross-section of the steel plate is created and it is extruded to form the three-dimensional macro-element cross-section (figure 3). The steel plates are then assigned the material properties and they are provided at support and loading points. It is necessary to generate the mesh for performing the finite element analysis. The demo version of ATENA 3D v4 supports only 300 elements, hence choose the mesh size accordingly. This work is done on ATENA 3D v4 demo version. The beam element and steel plates had meshed with brick element and tetrahedral element respectively (figure 4). Tetrahedral elements are generally not recommended for stress analysis but they can be used in this case for modelling the steel plates because accurate modelling of stresses and deformations in these areas is not as important as the modelling of the concrete beam itself [12]. Two reinforcement bars with a diameter of 26mm and a clear cover of 50mm are provided at the bottom surface of the beam.

After the beam modelling, the support and loading conditions are defined. Only the symmetric half of the beam is analysed, it is necessary to define the axis of symmetry along the right side of the beam. Therefore the horizontal x-displacements along the right side should be equal to zero [12]. The support condition should be defined such that it satisfies the above criteria. The other support conditions at the bottom steel plate was specified as fixed in the Y direction prevent any rigid body displacement. The prescribed displacement is applied to a single node to monitor the reaction forces at the node[12]. The prescribed deformation is applied by load acting in the vertical direction on the top steel plate.

Modelling of the beam, definition of support, and action is followed by definition of loading history. ATENA 3D v4 offers a set of standard solution parameters. Suitable solution parameters may be selected by the user. This work is based on the Newton-Raphson method and 40 load steps. During the non-linear analysis, it is helpful to monitor the forces, displacements, or stresses in the model. The monitoring data is useful to determine whether maximum load was reached or not in the structure. The deflection was monitored using the first monitoring point located at the point of

largest possible deflection. The second monitoring point was added near the joint, where the prescribed displacements are added. This monitoring point corresponds to the load value (figure4).

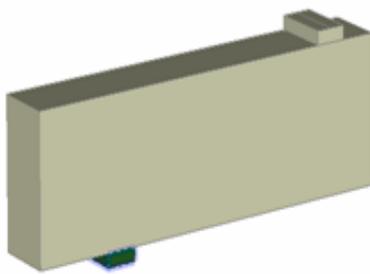


Figure 3: The generated half portion of the symmetrical beam

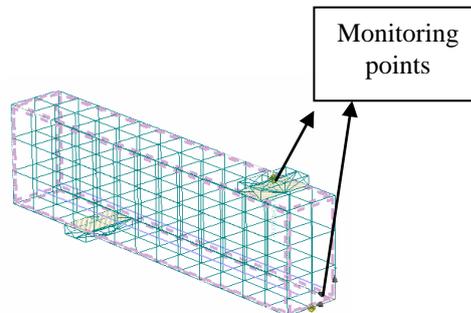


Figure 4: Beam with meshing and the position of monitoring points

### Run Analysis

The pre-processing includes generation of the beam, meshing, definition of support and action, and definition of monitoring points. The next phase is the run analysis where the load-deflection curve and the cracks observed may be seen. The minimum crack width is adjusted to 0.1mm and analysis is initiated. The load at which the first crack is observed at the tension and compression zone and the corresponding load steps are noted. The peak load and its load steps are noted during the run time. The load-deflection curve can also be obtained after the complete analysis.

### Post-processing

The results analysed in the run analysis are processed to a user-friendly format in this phase. The load step corresponding to cracking and peak loads are selected in the post-processing window and the stress and strain at the tension zone and the compression zone are obtained. The load-deflection graph analysed in the run phase is also taken from this post-processing window.

The above-explained procedures were conducted on all five variants of concrete to obtain the breaking load, cracking load, stress, and strain at the compression and tension zone. The results are compared to get an understanding on the performance of the variants of concrete. The results and inferences are detailed in the subsequent sections.

## IV. RESULTS

The behaviour analysed includes breaking load, cracking load at the compression and tension zone and stress, and strain at the compression and tension zone of the symmetrical half of the beam. The superior performer among the sustainable concrete variants is proposed based on these parameters of the symmetrical half of the beam.

### Breaking load

Breaking load is the load that fails the specimen by exceeding its capacity to withstand any further loads. The breaking load for various concrete variants is shown in figure 5. The highest breaking load among the five concrete specimens was obtained for the fly ash based geopolymer concrete and the lowest being recycled fine and coarse aggregate concrete. The better performance of geopolymer concrete may be due to quality and the quantity of fly ash, alkaline liquids, water, and aggregates, the efficiency of polymerization reactions, and the binding of geopolymer gel. The alkali used in the polymerisation reaction is made from pellets of high purity which led to higher performance. The inferior characteristics of recycled fine and coarse aggregate concrete may be due to the low quality of recycled aggregates and also due to the presence of hydrated cement paste which reduces the specific gravity and increases the porosity.

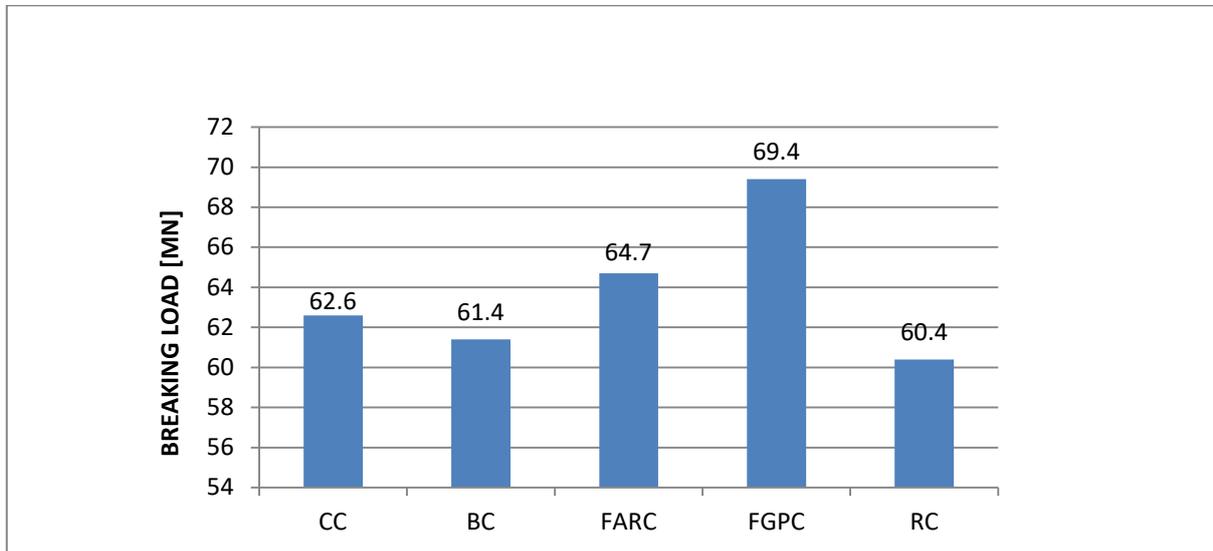


Figure 5: Breaking load for the various beam variants

### Cracking load

Cracking load is the load that causes cracks in members on exceeding the tensile strength of it. The cracking load for various concrete variants is shown in figure 6. Bacterial concrete performs well in the category followed by fly ash based geopolymer concrete and the lowest being recycled fine and coarse aggregate concrete. Bacterial concrete develops cracks in the tension zone at a very high load but near to the breaking load. The bacteria heal the cracks in concrete and hence the cracks are observed for the first time near the breaking load. The fly ash based geopolymer concrete develops a crack in the tension zone at a fairly good margin with the breaking load. The crack at the compression zone is seen to occur after the breaking load and hence its values are not significant from the structural point of view.

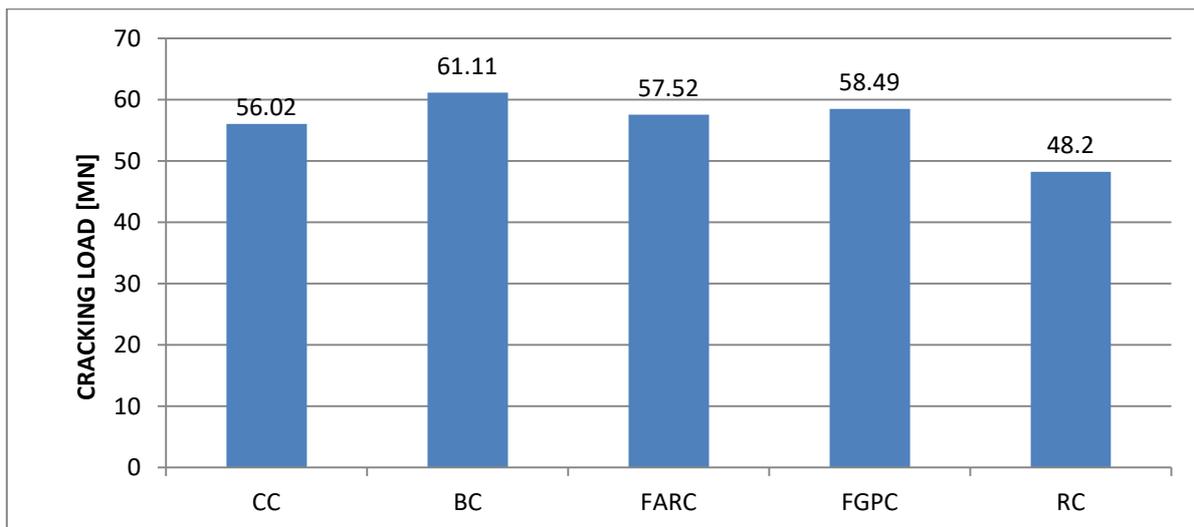


Figure 6: Cracking load for various beam variants at tension zone

### Stress and strain

The amount of stress in a body for a particular amount of strain helps to determine whether the body is rigid and stiff or is highly ductile. The stress and strain signify the lifetime of a component. The stress values were recorded at the



tension and the compression zone corresponding to the crack filter of 0.1mm. The cracks with a width greater than or equal to 0.1 mm are only considered in the analysis of cracking load and load steps. The trend observed revealed that the stress variations are more pronounced at the micro-cracks with a width less than 0.1mm. Hence it is not viable to compare the variants of concrete based on stress values. Finer results concerning stress may be obtained with a reduction in crack width.

Strain at the breaking load for various concrete variants is shown in figure 7. In bacterial concrete, the stress and strain at the breaking load and the stress and strain at the time of cracking appeared to be the same. The breaking load and the cracking load are so close that the stress and strain were also recorded as near values. Maximum strain at the tension side is seen in fibre added recycled aggregate concrete. The increase in elongation may be due to the presence of randomly oriented fibres in the concrete matrix. The strain at the compression side is the same for all the varieties except for recycled aggregate concrete. It may be due to the inferior quality of aggregate used. Elongation suffered by the fly ash based geopolymer concrete is similar to that of normal concrete. Hence fly ash based geopolymer concrete performs superior among the chosen varieties of concrete.

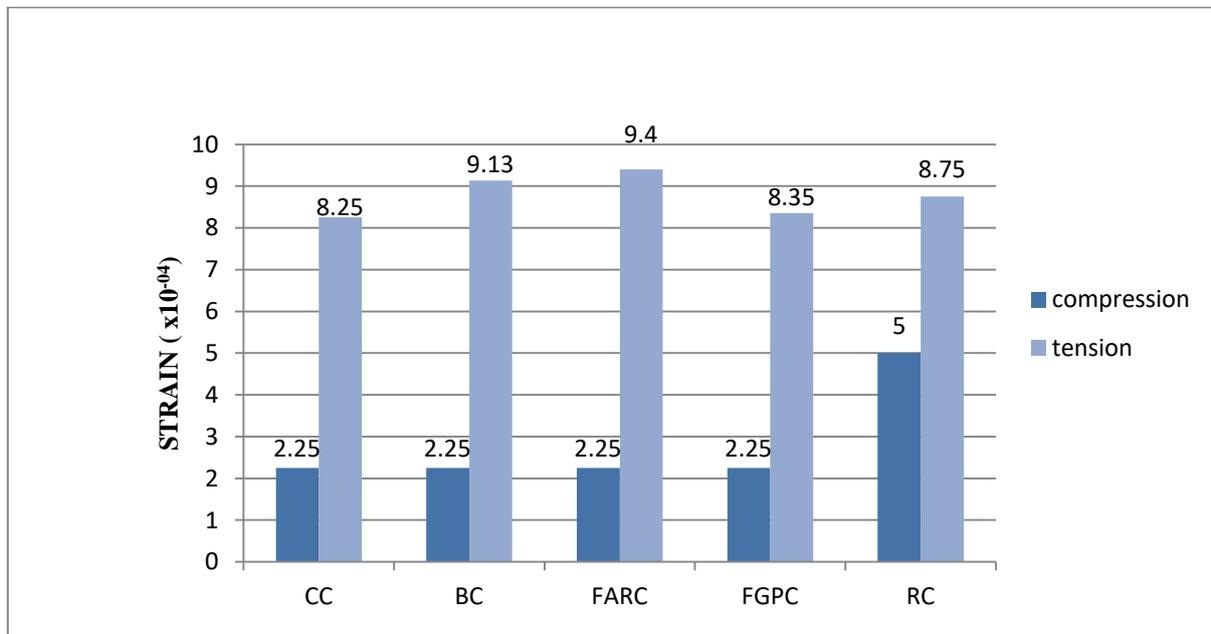


Figure 7: Stress and strain at the breaking load

### V. CONCLUSION

The flexural behaviour of conventional concrete, fibre added recycled concrete, recycled fine and coarse aggregate concrete, bacterial concrete, and fly ash-based geopolymer concrete were studied analytically by modelling a beam with the properties of concrete such as breaking load, cracking load, stress, and strain using the finite element method (FEM) tool ATENA. After the analysis, it was found that the fly ash based geopolymer concrete has performed well with regards to its ultimate strength which shows an increase of 10.86 % over conventional concrete. It's better performance is attributed to the quality of alkali used in the mix. NaOH is the alkali used in the polymerisation reaction and it is prepared from pellets of over 90% quality [11]. The fly ash based geopolymer concrete develop crack at greater load than conventional concrete. It shows 4.41% increase of cracking load over conventional concrete. The stress and strain of the variants were analysed at the point of breaking. It was observed that the strain in fly ash based geopolymer concrete was at par with the conventional concrete. Hence from all the considerations among the varieties of concrete, it can be concluded that the fly ash based geopolymer concrete has got a superior structural performance in terms of its flexural strength characterized by the ultimate load it carries. The strain associated with it is also satisfactory owing to its comparison with conventional concrete.



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