# NUMERICAL ANALYSIS OF CONCRETE BEAM USING METAKAOLIN WITH STEEL FIBERS.

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**Abstract— This research work is aimed to investigate the strength and durability characteristics of concrete beam with partial replacement of cement with Metakaolin and steel fiber and compare it with conventional reinforced concrete beam. The grade of concrete is M30 and the grade of steel is Fe415. The beam is subjected under two point concentrated load to enable a better understanding of the effects of span– depth ratio. For this investigation ANSYS FEA numerical software was used. The dimension of test specimens are 1000 mm x230 mm x 300 mm. The deflection of mid-span, the characteristics of the full process of stress-strain relationship, the failure mode and the load deflection deformation curve were examined. The numerical analysis results showed that the failure mode of Steel Fiber Reinforced Concrete beam with partial replacement of cement with Metakaolin differed from that of the conventional reinforced concrete beam, exhibiting enhanced crack resistance and delayed failure due to improved ductility and bond strength. From this numerical analysis the deformation is maximum at the midspan for both conventional reinforced concrete beam and steel fiber beam and minimum at edges. The stress and strain were maximum at the edges and minimum at the supports.**

**Key words: Metakaolin, steel fibers, ANSYS software, Numerical analysis.**

## I. INTRODUCTION

Global warming has emerged as one of the most critical environmental challenges of the 21st century. Among the major contributors to anthropogenic greenhouse gas emissions is the cement industry, which is responsible for approximately 8% of global carbon dioxide (CO2) emissions. In response to growing environmental concerns and the global push toward sustainable development, there is an increasing focus on identifying and incorporating alternative materials that can partially or wholly replace conventional cement in construction. Sustainable construction practices are guided by three primary pillars: environmental sustainability, economic feasibility, and social responsibility. Within this context, the present study investigates the partial replacement of coarse aggregate with stainless steel slag, a biomass-derived waste material, and the incorporation of Steel Fiber Reinforced as a reinforcing agent in concrete.

The increasing demand for sustainable and durable construction materials has led to the exploration of alternative resources and reinforcement systems in concrete structures. This study focuses on the combined use of Metakaolin as a partial replacement for coarse aggregate and steel Fiber bars as a substitute for traditional steel reinforcement in reinforced concrete beams. The objective is to evaluate the feasibility of using industrial waste materials and corrosion resistant reinforcement to enhance structural performance while reducing environmental impact. Concrete beam specimens are cast with varying proportions of steel slag and reinforced with SFRP bars, and are assessed for their mechanical properties, including strength and workability. The research aims to promote the use of eco-friendly materials in structural applications, contributing to the development of more sustainable construction practices.

## II. LITERATURE REVIEW

1) Prabeen Kumar Sahu*1, Niharika Patel*2 M.TECH Scholar, Department Of Civil Engineering, GIET University, Gunupur,India",. Concrete, in construction, a structural material consisting of binding material, fine aggregate, coarse aggregate and water. Today construction cost is very high with using

conventional material, due to unavailability of materials. This problem can be solved by replacement of concrete with different material which is not convenient in terms of required properties. Due to this limitation of unavailability of material which plays the vital role of concrete, we have only choice of partial replacement of concrete ingredients by different waste material and pozzolanic material. Today's annual global cement production has reached 2.8 billion tonnes and is expected to increase to some 4 billion tonnes per year. The cement production also emits co2 into the atmosphere which is harmful to the nature. If we partially replace the cement with material having desirable properties, then we can save natural material and reduce the emission of co2. In this experiment we will study the behaviour of concrete in which the cement will be partially replaced by Melakoalin..

2) Erhan Güneyisia,⇑, Mehmet Gesogˇlua, Arass Omer Mawlod Akoia, Kasım Mermerdas. This study reports the results of an experimental study on mechanical properties of plain and metakaolin(MK) concretes with and without steel fiber. To develop the metakaolin included steel fiber reinforced concrete mixtures, Portland cement was partially replaced with MK as 10% by weight of the total binder content. Two types of hook ended steel fibers with length/aspect ratios of 60/80 and 30/40 were utilized to produce fiber reinforced concretes. Two series of concrete groups were designed with water to binder ratios (w/b) of 0.35 and 0.50. The effectiveness of MK and different types of steel reinforcement on the compressive, flexural, splitting, and bonding strength of the concretes were investigated. All tests were conducted at the end of 28 days of curing period. Analyses of variance on the experimental results were carried out and the levels of the significance of the variables on the mechanical characteristics of the con-cretes were determined. Moreover, correlation between the measured parameters was carried out to bet-ter understand the interaction between mechanical properties of the concretes. The results revealed that incorporation of MK and utilization of different types of steel fibers significantly affected the mechanical properties of the concretes, irrespective of w/b ratio..

3) Jatinder Singh Kharb1, Sanjay Kumar Sharma2, During cement production, work has been conducted to examine the effect of metakaolin (MK) substitution with cement strength due to associated environmental pollution and to preserve virgin raw materials for future generations, and yet at the same time, utilizing the approachability of additional cementing materials such as metakaolin-an engineered material. In this study, the strength characteristics of Metakaolin concrete with and without crimped steel fiber have been tested. Reinforced concrete with short random fibers has been identified by monitoring the origin length/dia. propagation of fractures to enhance the strength of cementitious matrices. Steel fibers have contributed to mechanical qualities by minimizing the crack development inside concrete blocks and so improving concrete strength at all testing ages. Results show that the flexural strength of M60 concrete increases with 1.5 percentages of fiber content and strength-effectiveness at aspect ratio 60 is observed to be maximum.

4) Stephen Issac1 , Anju Paul2, The overall production of the cement has greatly increased which results lots of problems in environment as it involves the emission of CO2 gas. Environmental concerns, stemming from the high energy expense and carbon dioxide emission associated with cement manufacture have brought about pressures to reduce cement consumption through the use of supplementary materials. Materials such as Metakaolin, fly ash have good pozzolanic activity and are a good material for the production of high strength concrete which is getting popularity because of its positive effect on various properties of concrete. In this review the mechanical properties of Metakaolin and fly ash as a supplementary cementitious material are discussed.

5) V. V. Sawant1, Dr. C. P. Pise2, Prof. G. D. Lakade3 1PG Student, Civil Engineering, SKNSCOE, Korti, Pandharpur, Maharashtra, India 2Head of Department, Civil Engineering. SKNSCOE, Korti, Pandharpur, Maharashtra, India 3AssistantProfessor, Civil Engineering, SKNCOE, Korti, Pandharpur, Maharashtra, India.Abstract- The current paper presents the result and discussion of an experimental study on HSFRC using Metakaolin (MK). The effects of these fiber and Metakaolin on workability, density, and on various strengths of M60 grade concrete are studied. Fiber content varies from 2.5% to 10 % by weight of cement and Metakaolin content varies from 5% to 20%

by weight of cement. The various strengths considered for investigation are compressive strength, flexural strength, split tensile strength, and shear strength. Cubes of 150mm for compressive strength, cylinders of size 150mm diameter x 300mm length for split tensile strength, beams of 100 x100 x 500 mm for flexural strength, push-off specimens of size 150 x 150 x 450 mm for shear strength were cast. The prepared specimens were water cured and tested for variety of properties up to certain period of the time.

## III. METAKAOLIN,STEEL FIBERS AND CONVENTIONAL BEAM

Metakaolin is a by-product formed during the production and refining of clay, typically in Electric Arc Furnaces (EAF) and Argon Oxygen Decarburization (AOD) units. During this process, impurities in the steel (such as sulfur, silicon, phosphorus) are oxidized and combine with fluxes like lime (CaO) and dolomite ($CaMg(CO_3)_2$) to form slag.Stainless steel slag (SSS), a byproduct of clay production, shows significant potential for sustainable use in construction. It can be effectively utilized as a partial replacement for coarse aggregates in concrete, enhancing strength and durability while reducing reliance on natural resources.

Steel Fiber Reinforced (SFR) bars are composite reinforcement materials made by combining Steel fibers with a polymer resin matrix. These bars serve as an alternative to traditional steel reinforcement in concrete structures and are particularly valued for their high strength-to-weight ratio, corrosion resistance, and durability in aggressive environments.

A conventional beam is a fundamental structural element used extensively in construction and engineering to support loads and resist bending. Typically horizontal, conventional beams transfer applied loads primarily through bending moments and shear forces to supporting structures such as columns or walls. These beams are designed using classical beam theory, which assumes that the material behaves elastically under loading conditions. They are designed based on our requirement such as size, shape etc. Common materials used in conventional beams include reinforced concrete, steel, and wood, depending on the application and load requirements. They are classified based on their support conditions (simply supported, cantilever, fixed, continuous), cross sectional shapes (rectangular, I-beam, T-beam), and materials.

## IV. DIMENSIONS

The conventional beam has been designed for the length of 1500mm and width of 150mm and breadth of 150mm and 1300mm and width of 150mm and breadth of 150mm with Two-point loading condition. The support condition is fixed for both cases. The effective depth is calculated by l/3 ratio. The above specified beam is modelled in Abaqus CEA software and the deformation is noted

## V. REINFORCEMENT DETAILING

Two reinforced concrete beam specimens, designated as B1 and B2, were prepared and tested under fixed-end conditions. Beam B1 had dimensions of 1300 mm × 150 mm × 150 mm, while beam B2 measured 1500 mm × 150 mm × 150 mm. Both beams had a clear span of 1175 mm with an effective cover of 25 mm. Beam B1 was reinforced longitudinally with four 10 mm diameter bars, while beam B2 used four 12 mm diameter bars. For shear reinforcement, both beams were provided with 8 mm diameter two-legged stirrups spaced at 150 mm center-to-center along the span. The reinforcement detailing and dimensions were selected to ensure comparable conditions for evaluating the structural performance under similar loading and support constraints.

FIG 1: REINFORCEMENT DETAIL OF B1

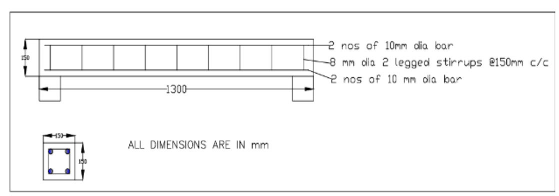
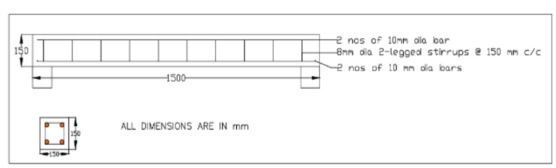



FIG 2: REINFORCEMENT DETAIL OF B2



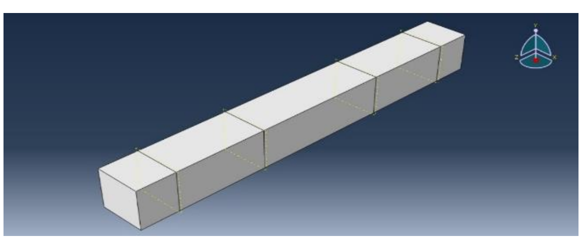
## VI.NUMERICAL ANALYSIS

The Finite Element Method (FEM) is a widely used numerical technique for solving differential equations commonly encountered in engineering and scientific modeling, particularly in the field of structural analysis. The core idea behind FEM is to break down a complex structure into a finite number of smaller, manageable elements connected at discrete points known as nodes. This approach simplifies the analysis of structures that would otherwise involve an infinite number of variables. Abaqus, a powerful FEM-based software, is well-suited for analyzing both static and dynamic problems. In a typical finite element model within Abaqus, the process involves several key steps: defining the part module, assigning material properties, creating instances of parts, discretizing the model into elements (meshing), setting up interactions and boundary conditions, and finally applying loads. This structured approach enables accurate and efficient analysis of structural behavior under various loading conditions.

## VII.RESULTS

The results obtained from the numerical and finite element analyses of the conventional beam provides a mid-span deflection for B1 and B2 the simulation is done on ANSYS. it reveals that the well-detailed detail about the conventional beam. The ANSYS module clearly shows the maximum deflection and maximum shear for the conventional beam B1 and B2. For both beam the failure occurs at midspan. The numerical analysis shows that the Deflection occurs at load of 64kN for 1.3 m length B1.the ANSYS modelling result for beam (B1) are represented as maximum deflection and maximum shear.

FIG 3: MODEL FOR B1



Breadth:150mm, depth :150mm, length: 1300mm

FIG 4: SHEAR REPRESENTATION OF BEAM(B1)

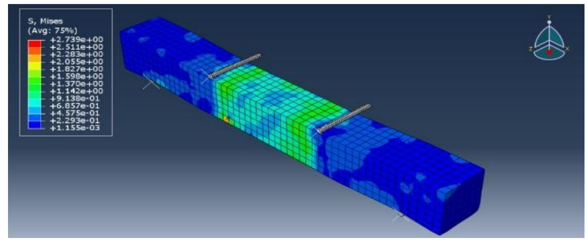


FIG 5: DEFLCTION OF BEAM (B1)

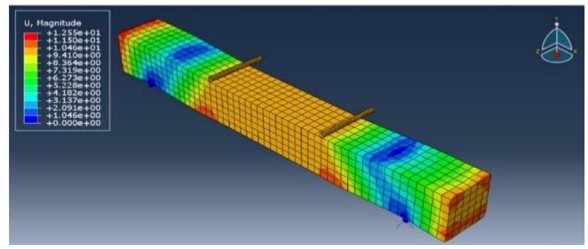
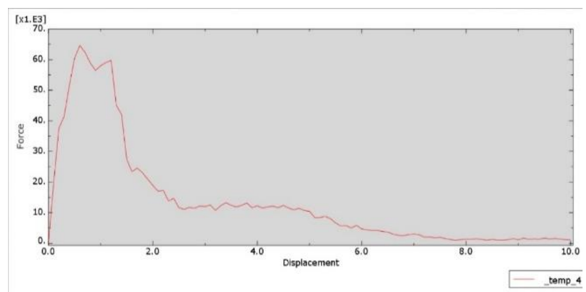
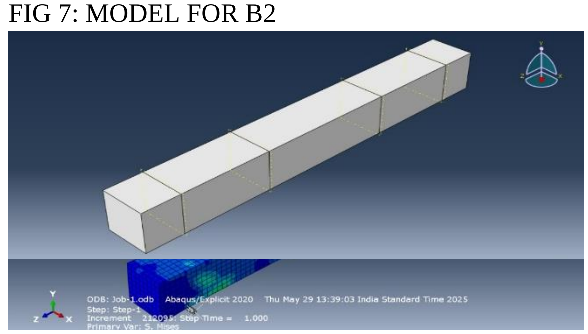


FIG 6: GRAPHICAL REPRESENTATION OF BEAM (B1)




The ANSYS module for beam (B2). The failure occurs at midspan. The numerical analysis shows that the Deflection occurs at load of 21kN for 1.5 m length B2. the ANSYS modelling result for beam (B2) are represented as maximum deflection and maximum shear.

FIG 7: MODEL FOR B2



Breadth:150mm, depth:150mm, length:1500mm

FIG 8 : DEFLECTION OF BEAM (B2)

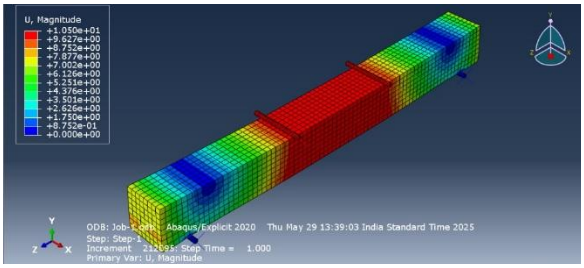
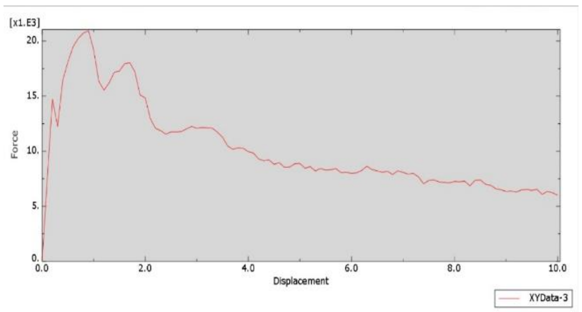



FIG 9: GRAPHICAL REPRESNETATION OF BEAM (B2)




## VIII.CONCLUSION

This project effectively demonstrates the potential of incorporating Metakaolin and Steel fibers into concrete to enhance both environmental sustainability and structural performance. The partial replacement of cement with Metakaolin not only helps address disposal issues of this invasive species but also improves the concrete's pore structure and compressive strength due to enhanced pozzolanic activity.Steel fiber reinforcement significantly improves the concrete's tensile strength, crack resistance, and overall durability, making it a viable alternative to steel reinforcement, especially in aggressive environments. Steel corrosion resistance and longer lifespan also contribute to reduced maintenance and lifecycle costs. The ANSYS simulation results clearly illustrate the superior performance of steel fiber reinforced concrete (SFRC) beams over conventional ones. Under increasing load conditions (50–400 kN), SFRC beams exhibited gradual deformation, linear stress-strain behaviour, and higher tolerance before failure, indicating enhanced structural integrity and ductility. The stress distribution and crack resistance patterns from ANSYS images confirm that SFRC beams sustain higher loads with reduced strain concentrations.Overall, this study confirms that the combined use of Metakaolin and Steel fibers in concrete offers an eco-friendly, cost-effective, and structurally superior alternative for modern construction needs..

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