NUMERICAL INVESTIGATION ON CONCRETE BEAM USING GFRP BARS WITH PARTIAL REPLACEMENT OF COARSE AGGREGATE WITH STAINLESS STEEL SLAG

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Abstract— The construction industry faces increasing pressure to adopt sustainable and durable materials due to the depletion of natural resources and long-term durability challenges associated with conventional reinforced concrete. This research aims to address these concerns by exploring the dual use of stainless steel slag as a partial replacement for coarse aggregate and Glass Fiber Reinforced Polymer (GFRP) bars as a corrosion-resistant alternative to traditional steel reinforcement in concrete beams. GFRP bars offer superior tensile strength, lightweight properties, and excellent resistance to corrosion and chemical attack, making them suitable for aggressive environments. Beam specimens were cast with varying percentages of stainless steel slag and reinforced with GFRP bars. The combined use of industrial waste and advanced non-metallic reinforcement aligns with global efforts toward green construction and offers practical insights into the application of alternative materials in structural concrete elements. From this numerical analysis the deformation is maximum at the midspan for both conventional reinforced concrete beam and SSS + GFRP bars beam and minimum at edges. The stress and strain were maximum at the edges and minimum at the supports. The behavior of gfrp rod reinforced beam is analyzed under 2 point load test. The FEM software ANSYS is used for analysis purpose. The ultimate load, deflection of the beams is studied. Finally, the results were interpreted.

Key words: Stainless steel slag, GFRP bars, 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 Glass Fiber Reinforced Polymer (GFRP) 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 stainless steel slag as a partial replacement for coarse aggregate and Glass Fiber Reinforced Polymer (GFRP) 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 GFRP 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) Zulmahdi Darwis et al., (2023): The study investigates the effect of substituting steel slag for coarse aggregate on the compressive strength of concrete and determines the optimal steel slag to normal concrete ratio. Concrete samples aged for three, seven, and 28 days were prepared using SNI 7656:2012, incorporating different proportions of steel slag as a substitute for coarse aggregate. Results indicate that variations of 20%, 40%, and 60% show improvements in comparison to normal concrete after three and seven days of curing. However, the variations of 80% and 100% are less commonly used than standard concrete. The increase in compressive strength of steel slag concrete aged 28 days, compared to normal concrete, for variations of 20%, 40%, and 60% is 1.54%, 3.00%, and 6.57%, respectively, while the reduction for variations of 80% and 100% is 7.93% and 18.80%. Based on the results, steel slag concrete with a 60% substitution of coarse aggregate exhibits the optimal compressive strength ratio in the mixture.

2) M.D. Rubio-Cintas,et al., (2019): This paper analyzes the mechanical behavior of concrete samples with the addition of an industrial waste, such as ferritic fume dust produced by electric arc furnaces (EAF) when the materials are melted and makes a comparison using other types of additions of concrete such us silica fume. At the same time this paper studies the capacity of the matrix to encapsulate this residue that eventually ends up deposited in a landfill. The results show that, besides giving the concrete a greater resistance as it happens with silica fume, the use of this type of waste as an addition to concrete is suitable since the material remains encapsulated in the concrete matrix, thus not producing leaching of heavy metals which can be harmful to the environment and therefore to the health of the human being.

3) Julia Rosales et.al.,(2020): This work shows the feasibility of using stainless steel slag as a substitute for limestone filler in the manufacture of self-compacting concrete. The influence of different treatments applied to slags on physical and chemical properties was studied. On the other hand, the mechanical behaviour, as well as the durability acquired in self-compacting concrete, has been analysed. Very encouraging results were obtained, since this research demonstrates the possible application of this stainless steel slag as a construction material, improving sustainability and promoting circular economy processes, which are achieved through the minimisation of the waste disposal and accumulation.

4) Khaled Mohamed,et al., (2017): This study uses nonlinear finite-element analysis (FEA) to perform an in-depth investigation. FEA response was compared against the experimental results in terms of crack patterns, failure modes, strains in reinforcement and concrete, and load–deflection relationships. The results show that the simulation procedures employed were stable and compliant, and that they provided reasonably accurate simulations of the behavior. FEA was used to confirm some hypotheses associated with the experimental investigations. A comprehensive parametric study was conducted to investigate the effect of web reinforcement and loading-plate size on the strut efficiency factor. It was shown that vertical web reinforcement has no clear effect on the strength, but it is required for crack control. On the other hand, horizontal web reinforcement should be accompanied with vertical reinforcement. Loading-plate size showed a clear effect on the deep-beam strength. Based on the numerical simulation results, a modification to a recently proposed STM is suggested. The modified STM was compared to available STMs in design codes and provisions, yielding better correlation with experimental results.

5) Anjali Kumari Pravin Kumar Pandey et al., (2024): This paper aims to provide insights into the structural characteristics of concrete columns reinforced with Fiber Reinforced Polymer (FRP) rebars, specifically GFRP bars, as alternatives to steel bars. It examines the influence of parameters such as aspect ratio, concrete type and grade, slenderness ratio, and reinforcement percentage on the strength and ductility of GFRP RCC columns under axial and eccentric loads. Design equations and numerical methods for predicting load-carrying capacity are summarized. The literature review reveals that GFRP RCC columns have 80–100% of the strength of steel RCC columns under concentric loading and 60–103% under eccentric loading, with a higher ductility

index than steel RCC columns by an average of 17.4%. For NSC and HSC columns, GFRP bars contribute about 50% of the axial load-carrying capacity compared to steel bars. From the literature review in predicting the design load-bearing capacity of GFRP-RCC columns.

III. STAINLESS STEEL SLAG WITH GFRP BARS AND CONVENTIONAL BEAM

Stainless steel slag is a by-product formed during the production and refining of stainless steel, 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 stainless steel 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.

Glass Fiber Reinforced Polymer (GFRP) bars are composite reinforcement materials made by combining glass 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 1000mm and width of 230mm and depth of 300 mm 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 ANSYS 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 1000 mm × 230 mm × 300 mm. Beams had a clear span of 900 mm with an effective cover of 25 mm. Beam used four 12 mm diameter bars. For shear reinforcement, 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.

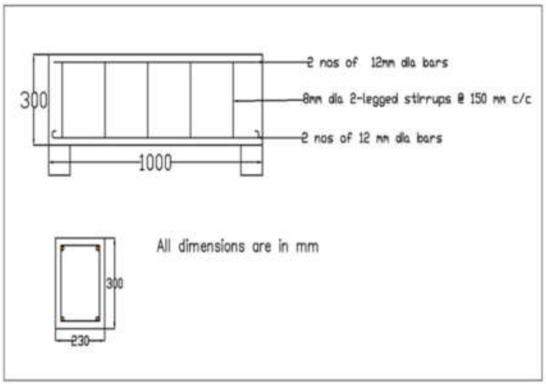

Figure 1: Beam cross section

The reference diagram is drawn using AUTOCAD software

VI.NUMERICAL ANALYSIS

The model of 1000mm long with a cross section of 230 mm x 300 mm is fabricated. Concrete structure is modeled in ANSYS SPACECLAIM software and this model is imported in analyzing software (ANSYS MECHANICAL). Material properties are applied on the model. In this beam M30, grade of self-compacting geo polymer concrete is used to enhance the mechanical properties of the beam.

VII.RESULTS

The results obtained from the numerical and finite element analysis of conventional beam provides a mid-span deflection for beam the simulation is done on ANSYS. It reveals that the well-detailed about the beams. The module shows the maximum deformation, von mises stress and stain.

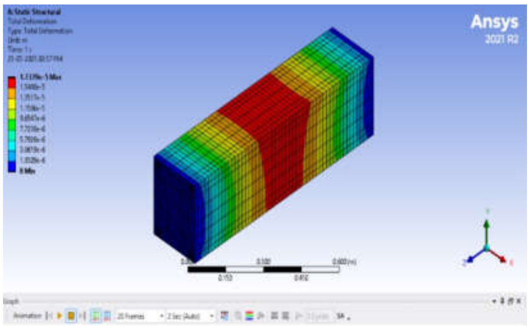

Figure 2: Total deformation of conventional beam

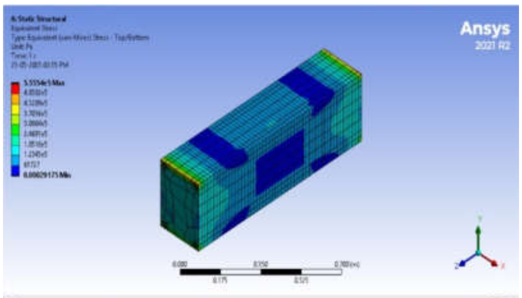

Figure 3: Total stress of conventional beam

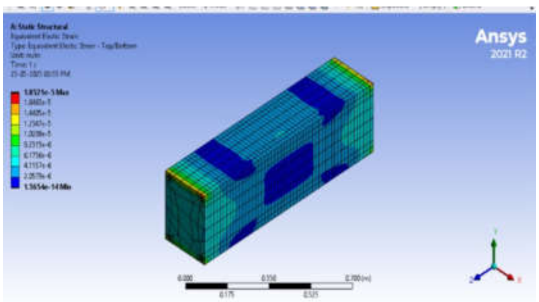

Figure 4: Total strain of conventional beam

Load (kN)	Stress (N/mm^2)	Strain	Deformation (mms)
0	0	0	0
200	6.44	257.6	0.283
250	8.05	322	0.354
300	9.67	386.8	0.425
350	11.28	451.2	0.496
400	12.89	515.6	0.566
450	14.5	580	0.637
500	16.11	644.4	0.708
550	17.72	708.8	0.779
600	19.33	773.2	0.85
650	20.94	837.6	0.921
700	22.56	902.4	0.991
750	24.17	966.8	1.062
800	22.78	1031.2	1.133

Table 1: Values of deformation, stress and strain for different loads for conventional beam

The results obtained from the numerical and finite element analysis of SSS + GFRP beam provides a mid-span deflection for beam the simulation is done on ANSYS. It reveals that the well-detailed about the beams. The module shows the maximum deformation, von mises stress and stain.

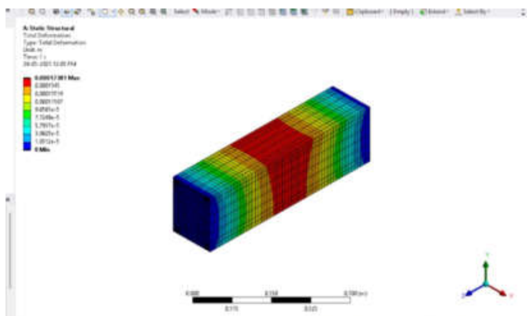

Figure 5: Total deformation of GFRP beam with SLAG

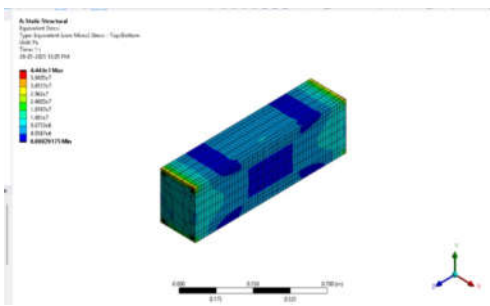

Figure 6: Total stress of GFRP beam with SLAG

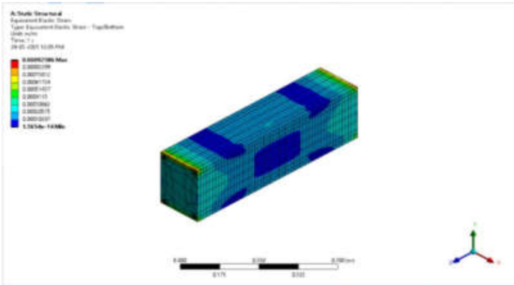

Figure 7: Total strain of GFRP beam with SLAG

Load (kN)	Stress (N/mm²)	Strain	Deformation (mm)
0	0	0	0
200	9.6618	386.47	0.5487
250	12.0773	483.09	0.6859
300	14.4928	579.71	0.823
350	16.9082	676.33	0.9602
400	19.3237	772.95	1.0974
450	21.7391	869.57	1.2346
500	24.1546	966.18	1.3717
550	26.57	1062.8	1.5089
600	28.9855	1159.42	1.6461
650	31.401	1256.04	1.7833
700	33.8164	1352.66	1.9204
750	36.2319	1449.28	2.0576
800	32.6473	1545.89	2.1948

Table 2: Values of deformation, stress and strain for different loads for GFRP beam with SLAG

VIII.CONCLUSION

This project effectively demonstrates the potential of incorporating Stainless steel slag and GFRP bars into concrete to enhance both environmental sustainability and structural performance. The partial replacement of Coarse aggregate with Stainless steel slag 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. Glass fibre reinforcement significantly improves the concrete's tensile strength, crack resistance, and overall Strength, making it a viable alternative to steel reinforcement, especially in aggressive environments. Glass corrosion resistance and longer lifespan also contribute to reduced maintenance and lifecycle costs.The ANSYS simulation results clearly illustrate the superior performance of Glass fiber reinforced Polymer (GFRP) beams over conventional ones. Under increasing load conditions (0–800 kN), GFRP 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 GFRP+SSS beams sustain higher loads with reduced strain concentrations.Overall, this study confirms that the combined use of Stainless steel slag and Glass fiber Reinforced polymer in concrete offers an eco-friendly, cost-effective, and structurally superior alternative for modern construction needs.

REFERENCES

1. "Experimental study on basic mechanical properties of basalt fiber reinforced concrete", H Zhou, B Jia, H Huang, Y Mou - Materials, 2020 - mdpi.com.Qian, G.L. Experimental study on reinforced concrete simply supported deep beams. J. Wuhan Inst. Water Resour. Electr. Power 1980, 4, 25–34.

2. "Flexural behaviour of reinforced concrete beam using basalt fiber" - October 2020, Manibalan P., SRM Institute of Science and Technology, Baskar Rajaram Annamalai University, Pannirselvam Narayanan, SRM Institute of Science and Technology.

3. International Journal of Civil Engineering and Technology (IJCIET). Volume 8, Issue 3, March 2017, pp. 1103–1111 Article ID: IJCIET_08_03_113. Available http://www.iaeme.com/IJCIET/issues.asp?JType=IJCIET&VType=8&IType=3
ISSN Print: 0976-6308 and ISSN Online: 0976-6316.
"Modelling and analysis of Rc beam under flexure using Ansys". Diyyala Naga Moulika, B. Tech Student, Department of Civil Engineering, KL University, Vaddeswaram, Andhra Pradesh, India, Reshma Vasireddy, B. Tech Student, Department of Civil Engineering, KL University,
Vaddeswaram, Andhra Pradesh, India, P. Polu Raju,

Associate Professor, Department of Civil Engineering, KL University,, Vaddeswaram, Andhra Pradesh, India.

4. Asian journal of Civil Engineering (BHRC) VOL. 14, NO. 4 (2013) "Finite element analysis of FRC strengthened RC beam using Ansys , P. Jayajothi, * R. Kumutha and K. Vijai, Department of Civil Engineering (PG), Sona College of Technology, Salem, India. Received: 10 October 2012; Accepted: 8 February 2013.

5. Finite Element Modeling and Simulation with ANSYS Workbench, Second Edition, ByXiaolin Chen, Yijun Liu.

6. "Utilization Of Steel Slag Waste As A Substitute For Coarse Aggregate In Concrete Mixture", October 2023, By, Zulmahdi Darwis*, Woelandari Fathonah, Lukmanul Hakim.

7. "Mechanical-Strength Characteristics Of Concrete Made With Stainless Steel Industry Wastes As Binders", April 2019, By M.D. Rubio-Cintas,Et Al.,

8. "Potential Of Stainless Steel Slag Waste In Manufacturing Self-Compacting Concrete", April 2020, By Julia Rosales Et.Al.,

9. "Nonlinear Finite-Element Analysis For The Behavior Prediction And Strut Efficiency Factor Of Gfrp-Reinforced Concrete Deep Beams", April 2017, By Khaled Mohamed,Et Al.,

10. "A Comparative Review On The Structural Behaviour Of Gfrp Rebars With Conventional Steel Rebars In Reinforced Concrete Columns", September 2024,By Anjali Kumari Pravin Kumar Pandey Et Al.,

11. "Flexural Behaviour Of Reinforced Concrete Beam Using Basalt Fiber" October 2020, Manibalan P., Srm Institute Of Science And Technology, Baskar Rajaram Annamalai University, Pannirselvam Narayanan, Srm Institute Of Science And Technology.

12. "Finite Element Analysis Of FRP Strengthened RC Beams Using ANSYS", P. Jayajothi, R. Kumutha And K. Vijai, Department Of Civil Engineering (PG), Sona College Of Technology, Salem, India.