

Structural Performance of Fibre Reinforced Ternary Blended Concrete Beams Containing Nano Alumina and Alccofine

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Abstract— This research investigation focuses on evaluating the impact of introducing steel fibers on the effectiveness of concrete beams incorporating nano alumina and alccofine. The study involved the casting and testing of a total of six beams, each measuring 150 mm x 250 mm in cross-section and 3000 mm in length. These beams underwent testing under static loading conditions. The evaluation of beam performance encompassed various parameters, including the first crack load, deflection at the first crack load, yield load, deflection at the yield load, ultimate load, deflection at the ultimate load, deflection ductility, deflection ductility ratio, energy ductility, and energy ductility ratio. The findings derived from the test results unequivocally demonstrate a substantial enhancement in the performance of concrete beams containing nano alumina and alccofine when steel fibers are incorporated, evident across all measured criteria.

Keywords:alccofine,cracking,deflection,ductility,energycapacity,fibrereinforcedconcrete,nanoalumina,strength

Introduction

Cement has been a pivotal binding material in the construction industry for many years, primarily owing to the ready availability of its raw materials. However, the escalating demand for cement, propelled by population growth and increased construction activities, presents a concerning trajectory. Projections indicate that by the year 2030, India alone will require 550 million tons of cement, facing a shortfall of 230 million tons. One major drawback of cement production lies in its substantial demand for raw materials and its annual emission of 5-7% of total greenhouse gases during the manufacturing process. To forge a sustainable path forward and meet the burgeoning demand for concrete, the construction industry must actively seek alternative binding materials with minimal environmental impact. In response to this imperative, some researchers have directed their efforts towards exploring alternative binding materials to partially replace cement, utilizing supplementary cementitious materials. Industrial byproducts from thermal power plants, steel industries, rice industries, and mining operations—such as fly ash, rice husk ash, GGBFS, alccofine¹²⁰³, silica fume, and metakaolin—pose an environmental threat if improperly disposed. The substantial quantity of land required for their disposal accentuates the urgency to repurpose

these byproducts either as cement replacements or as supplementary materials, contributing to the development of environmentally friendly green concrete. With industries generating copious amounts of byproducts annually, their improper disposal not only causes water pollution but also poses a significant threat to the environment. Heightened awareness of the environmental repercussions of solid waste disposal has prompted researchers to consider industrial byproducts as viable construction materials. The incorporation of pozzolanic materials not only curtails cement consumption but also augments the strength and durability of concrete structures.

The integration of steel fibers into concrete has been proven to enhance its post-crack resistance, ductility, toughness, fatigue strength, and impact strength [6]. Furthermore, the combination of silica fume with recycled steel fiber has been identified as a strategy to amplify impact resistance and overall mechanical properties [7]. Another promising avenue involves incorporating nano silica and mineral fibers, a practice known to expedite the cement hydration process. This acceleration, in turn, leads to a notable augmentation in the physical and mechanical characteristics of fiber-cement composites [8]. These findings underscore the versatility and potential of various additives in optimizing concrete properties, presenting

opportunities for tailored enhancements in both structural and performance aspects.

A. RESEARCH SIGNIFICANCE

In recent times, a significant shift in the approach to enhancing concrete performance in challenging environments has unfolded. Researchers are actively exploring avenues to modify concrete properties by incorporating innovative replacement materials for both cement and aggregates, ushering in a broad spectrum of materials for consideration. However, a notable challenge arises in achieving early age strength, as these materials exhibit limited reactivity in the initial stages. A novel perspective suggests that overcoming this practical hurdle can be facilitated through the introduction of minute quantities of nano-fillers, such as nano silica, nano alumina, nano clay, and the like. Notably, nano-fillers demonstrate heightened pozzolanic activity, especially during the early stages, surpassing the reactivity of micro-fillers. Within this framework, the ongoing research endeavors focus on investigating the impact of introducing steel fibers on the mechanical properties of concrete containing nano alumina and Alccofine. The experimental findings from this research provide valuable insights and draw pertinent conclusions regarding the efficacy of this approach.

I. EXPERIMENTAL PROGRAM

A. Materials

The concrete employed in this research exhibited a compressive strength of 33 MPa. The concrete mixtures were meticulously prepared using OPC 53 grade cement, sourced from Dalmia Cements, with a specific gravity of 3.15. Maintaining a water/binder ratio of 0.48, the composition also included a combination of locally available natural river sand (55%) and M-sand (45%), adhering to the specifications outlined in IS 383:2016 [30] for fine aggregates. Coarse aggregates were composed of crushed granite with a maximum particle size of 20mm, conforming to IS2386:2016 [31]. The specific gravity of fine and coarse aggregates was recorded at 2.67 and 2.72, respectively. For reinforcement, hooked end steel fibers, provided by Stewols India (P) Ltd., Nagpur, were incorporated into the mix. Various fiber volume fractions, specifically 0.5%, 1%, and 1.5%, were

systematically experimented with in the course of this study, contributing to a comprehensive exploration of their impact on concrete properties. Incorporating innovative materials, nano alumina and alccofine were introduced as partial replacements for cement in this study. The specific characteristics of the nano alumina and alccofine utilized are detailed in Table 1. To ensure the desired workability and strength parameters, a superplasticizer was also employed in the concrete mix. A Sulphonated Naphthalene-based superplasticizer, conforming to the standards outlined in ASTM C494[33], was chosen for its effectiveness in enhancing the fluidity of the concrete mixture while maintaining the requisite strength. This strategic combination of nano materials and a carefully selected superplasticizer aims to optimize the performance and properties of the concrete in line with the study's objectives.

TABLE1 PROPERTIES OF NANO ALUMINA AND ALCCOFINE

Properties	Nano Alumina	Alccofine
Colour	White	White
Specific surface area	202 m ² /g	12 m ² /g
Specific gravity	1.20	2.94

B. Mix Proportion

The experimental phase of this study involved the examination of six distinct concrete mixes, each incorporating 20% alccofine, 1% nano alumina, and different proportions of steel fibers (0.5%, 1%, and 1.5%). The identification and nomenclature for all test specimens are systematically outlined in Table 2, facilitating clarity and reference throughout the study. Detailed information regarding the composition of each concrete mix can be found in Table 3, offering a comprehensive insight into the varying proportions of alccofine, nano alumina, and steel fibers incorporated into the experimental setups. This structured approach allows for a meticulous examination of the impact of these components on the performance and properties of the concrete specimens.

TABLE2 NOMENCLATURE OF TEST SPECIMENS

Description
CCS(AF-0,NAL-0): Control concrete specimen with 0% of alccofine and Nano alumina
A-S: Specimen with 20% alccofine

ANS: Specimen with 20% alccofine and 1% Nano-alumina
ANS-1: Specimen with 20% alccofine ,1% Nano-alumina and 0.5% steel fiber
ANS-2: Specimen with 20% alccofine ,1% Nano-alumina and 1.0% steel fiber
ANS-3: Specimen with 20% alccofine ,1% Nano-alumina and 1.5% steel fiber

at 125mm centres. Fig. 1 shows the reinforcement details of the beam specimens.

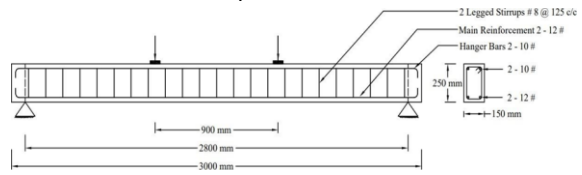


Fig. 1. Reinforcement Detailing of Test Beams

D. Test Instrumentation and Loading

Six beams underwent testing using a four-point bending setup within a 500 kN capacity loading frame. Positioned with hinge support at one end and roller support at the other, the beams featured a 100 mm bearing at both ends, resulting in a test span of 2800 mm. The detailed configuration of the test setup is illustrated in Fig. 2. To apply two-point loads, a spreader beam was utilized, and deflections were precisely measured at mid-span and load points using mechanical dial gauges with a 0.01 mm accuracy. Crack width assessment employed a crack detection microscope with a least count of 0.02 mm. Throughout the testing process, the evolution and propagation of cracks were continuously monitored, with all measurements recorded at various load levels until failure occurred.

TABLE 3 COMPOSITION OF CONCRETE MIXES

Mix No.	Specimen	W/Cement Ratio	Water Content (kg)	Cement (kg)	AF (kg)	NAL (kg)	Coarse Aggregate (kg)	Fine Aggregate (kg)
1	CCS (AF-0, NAL-0)	0.48	168	387	0	0	1219	654
2	A-S	0.48	168	309.6	77.4	0	1219	654
3	ANS	0.48	168	305.73	77.4	3.87	1219	654
4	ANS1	0.48	168	305.73	77.4	3.87	1219	654
5	ANS2	0.48	168	305.73	77.4	3.87	1219	654
6	ANS3	0.48	168	305.73	77.4	3.87	1219	654



Fig. 2. Test Setup

II. TEST RESULTS AND DISCUSSION

The findings from the experimental investigation, encompassing six beams comprising the control beam (CCS), ternary blended concrete beam (AS, ANS), and steel fiber-reinforced ternary blended concrete beams (ANS1–ANS3), are visually represented in Figures 3 to 9.

C. Details of Test Beams

A total of six beams were cast and tested for this study. The beams were 150 mm x 250 mm in crosssection and 3000mm long. The beams were reinforced with two numbers of 12mm diameter bars at bottom, two numbers of 10mm diameter bars at top and two-legged 8mm diameter stirrups

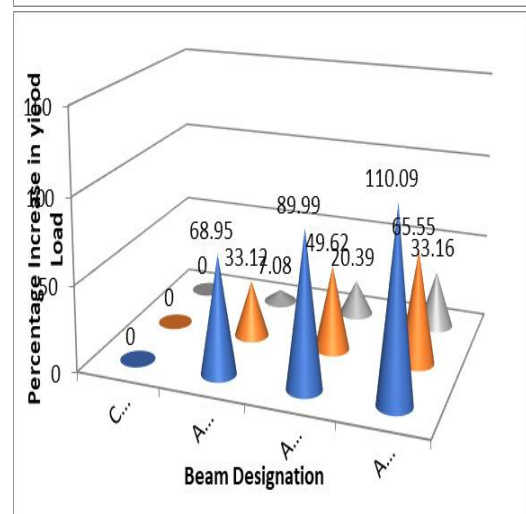
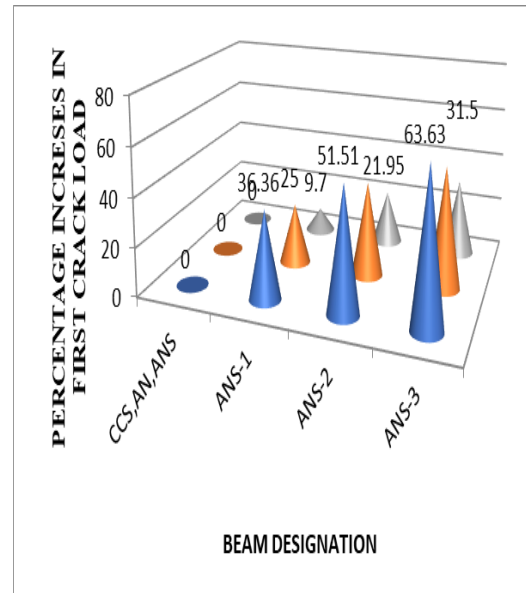
A. Effect on Strength and Deflection

At the first-crack stage (the corresponding load was obtained by visual examination only), the beam ANS3 (with 20% AL, 1% NAL and 1.5% fibre volume fraction) showed an increase of 63.63% in

load capacity over the control beam CCS(with0%ALand0%NAL), ANS3 (with 20% AL, 1% NAL and 1.5% fibre volume fraction) showed an increase of 50% in load capacity over the control beam ANS(with20%ALand0%NAL), ANS3 (with 20% AL, 1% NAL and 1.5% fibre volume fraction) showed an increase of 31.5 % in load capacity over the control beam ANS(with20%ALand1%NAL), At the yield stage (the corresponding load was obtained from the load-deflection plot), the load capacity of the beamANS3was110.09% higher than the control beam CCS(with0%ALand0%NAL).ANS3 (with 20% AL, 1% NAL and 1.5% fibre volume fraction) showed an increase of 65.55% in load capacity over the control beam. A-S(with20%ALand0%NAL),ANS3 (with 20% AL, 1% NAL and 1.5% fibre volume fraction) showed an increase of 33.16% in load capacity over the control beam ANS(with20%ALand1%NAL),The beam ANS3 provided a load capacity 45% more than the control beam CCS(with0%ALand0%NAL) at the ultimate stage.ANS3 (with 20% AL, 1% NAL and 1.5% fibre volume fraction) showed an increase of 38.09% in load capacity over the control beam A-S(with20%ALand0%NAL),ANS3 (with 20% AL, 1% NAL and 1.5% fibre volume fraction) showed an increase of 31.81 % in load capacity over the control beam ANS(with20%ALand1%NAL), The enhanced strength observed at every stage of loading can be attributed to the elevated tensile strength of the fibers, the reinforcing stitching effect produced by the fibers, and the improved bond established between the matrix and the aggregates.

The beam ANS3 showed an increase of 88.72% in deflection compared to the control beam CCS(with0%ALand0%NAL)at the first crack stage. The beam ANS3 showed an increase of 45.28% in deflection compared to the control beam AS (A-S(with20%ALand0%NAL))at the first crack stage. The beam ANS3 showed an increase of 41.54% in deflection compared to the control beam ANS (20%ALand1%NAL)at the first crack stage. The increase in deflection was 38.22% for the beam ANS3 over the control beam CCS(with0%ALand0%NAL) at the yield stage.The increase in deflection was 22.42% for the beam ANS3 over the control beam AS(with20%ALand0%NAL)at the yield stage. The increase in deflection was 14.41% for the beam

ANS3 over the control beam ANS(with20%ALand1%NAL)at the yield stage. The beam ANS3 exhibited an increase of 88.38% in deflection in comparison to the control beam CSS at the ultimate stage.The beam ANS3 exhibited an increase of 62.15% in deflection in comparison to the control beam AS at the ultimate stage. The beam ANS3 exhibited an increase of 44.74% in deflection in comparison to the control beam ANS at the ultimate stage The enhancement in deflection capacity may be due to the higher elasticity modulus of fibres and the improved bond between the matrix and the fibres. The outcomes pertaining to load and deflection were illustrated in Figures 3 and 4, respectively.



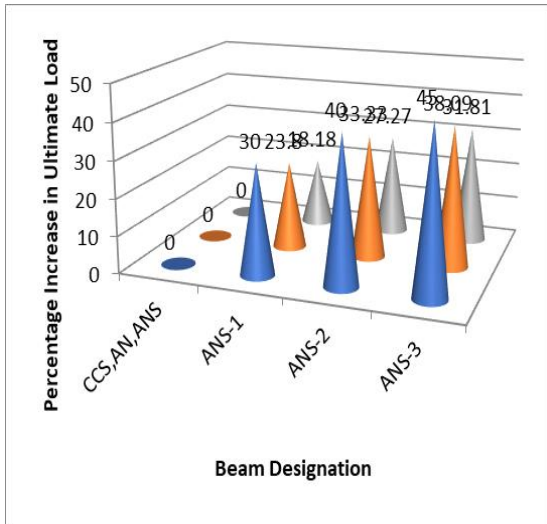


Fig. 3. Effect on Strength

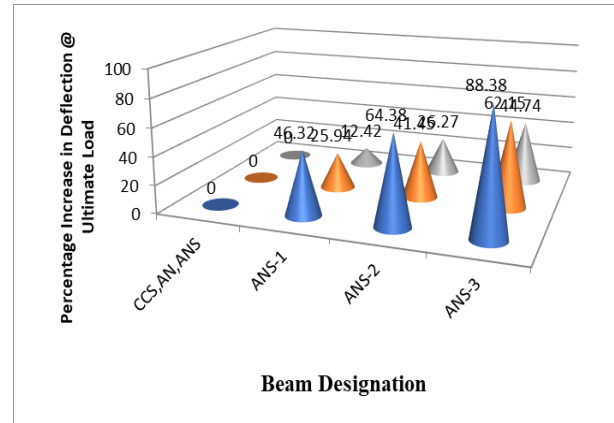
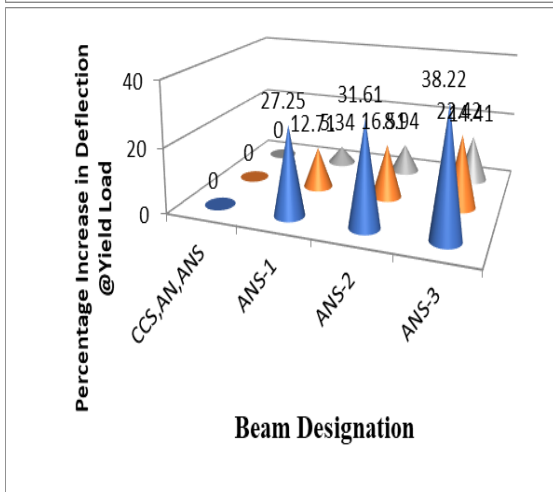
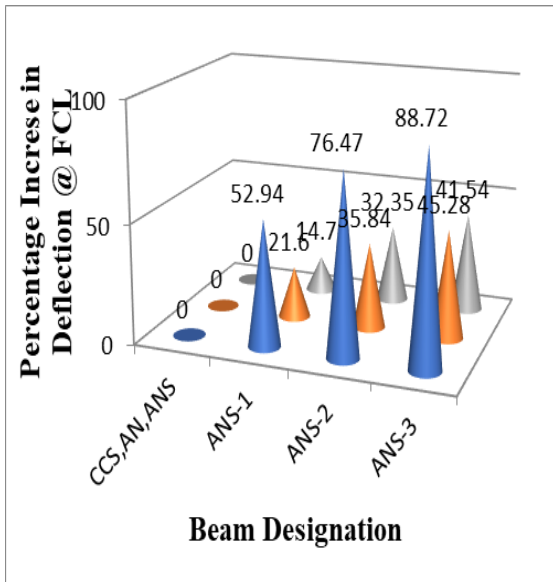


Fig. 4. Effect on Deflection



B. LoadDeflectionRelationship

The experimental assessment involved measuring the loads borne by each test beam at distinct stages, namely, the first crack, yield, and ultimate stages. Simultaneously, the deflection experienced by the beam specimens was meticulously gauged using appropriate instrumentation throughout the loading stages.

The load-deflection response curves for all the beam specimens subjected to testing in this study are depicted in Figure 5. Initially, the curves exhibited linearity up to the first crack stage, but as the loading increased, the slope gradually decreased. Concurrently, the beam displayed an escalation in the number of cracks. As the load further increased, the reinforcing steel began yielding, causing a significant decrease in the slope of the curves. This phase was characterized by heightened deflections, an increased count of cracks, and a larger crack size. The cracks also extended towards the compression face of the beam, a pattern that persisted until reaching the ultimate stage.

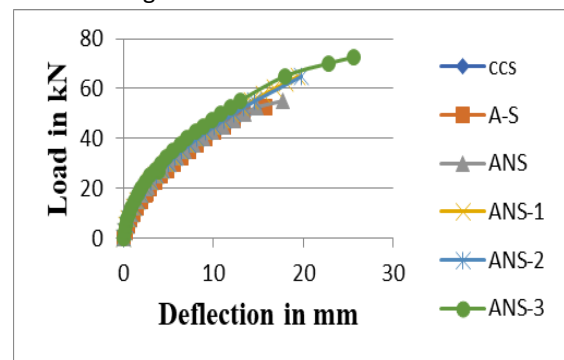
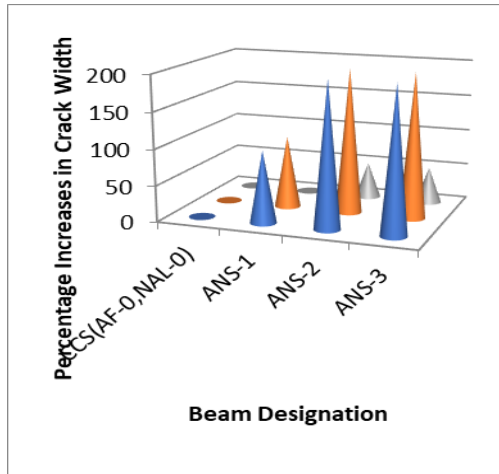


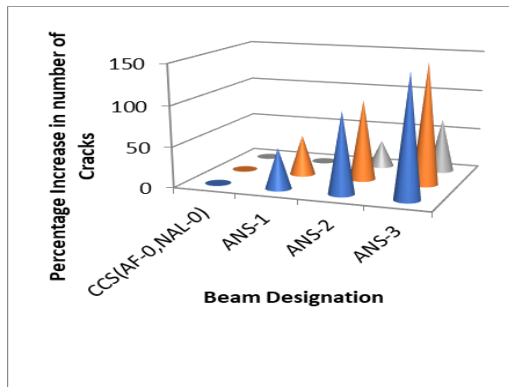
Fig. 5. Load Vs.DeflectionPlot

C. Evolution of Cracks and Modes of Failure

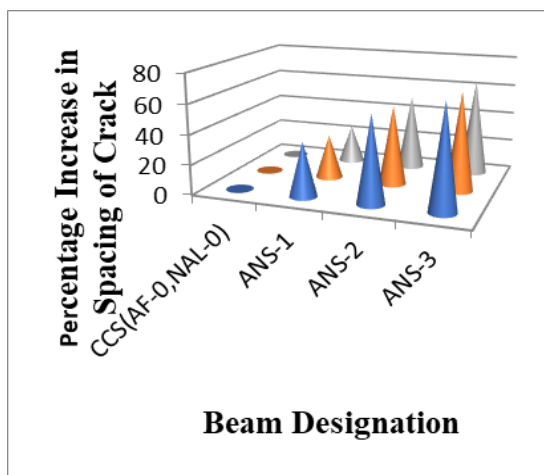
The crack width, number of cracks, and the average spacing of cracks at the ultimate stage are depicted in Figure 6. Observing Figure 6 reveals a reduction in crack width and a higher count of cracks in steel fiber-reinforced ternary blended concrete beams compared to the control beams AS and ANS. This phenomenon is likely attributed to the increased resilience of the micro-fibers.



(a)



(b)



(c)

Fig. 6. (a)Crack Width,(b)Number of Cracks,(c)Spacing of Cracks

The crack distribution for all the beam specimens examined in this study is presented in Figure 7. During the initial loading stages, hairline cracks were noticeable in the constant moment zone.



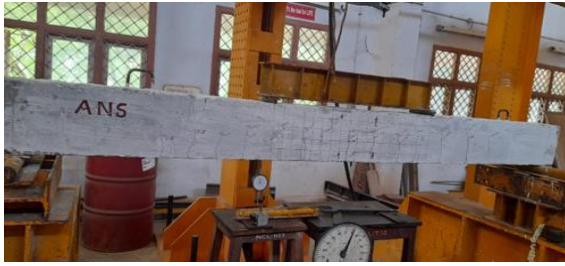


Fig. 7. Crack Patterns of Tested Beams

D. Ductility Index

The ductility of a beam represents its capacity to withstand elastic deformation without experiencing a reduction in load-carrying capability, leading up to failure. Ductility can be quantified in terms of deformation or energy. In this investigation, the ductility indices for all the tested beam specimens are illustrated in Figure 8. Analysis of the results in Figure 8 indicates a distinct impact of fiber inclusion on beam ductilities. As the fiber volume fraction increased, ductility exhibited a corresponding improvement. Notably, Beam ANS3 demonstrated the highest increase, registering a 36.07% rise in deflection ductility compared to the control beams AS and ANS. This significant enhancement in ductility can be attributed to the heightened resilience of the micro-fibers and the improved bond at the matrix-fiber interface.

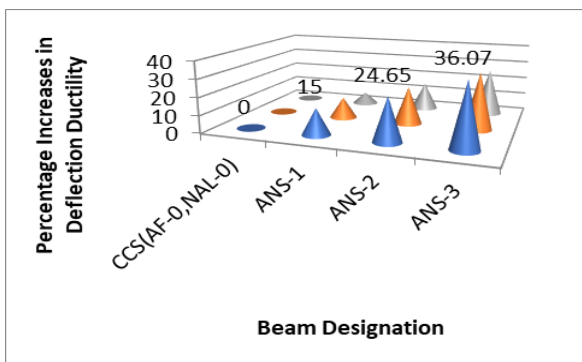


Fig. 8. Effect on Beam Ductility

E. Energy Capacity

The energy capacity of all the beam specimens subjected to testing in this study is outlined in

Figure 9. It is well-established that, for any structural member, a greater ductility corresponds to a larger energy capacity. The evaluation of energy capacity is conducted by assessing the area beneath the load-deflection response plots. Notably, the energy capacity exhibited an upward trend with an increase in the fiber volume fraction. Beam ANS3, in particular, demonstrated the most substantial increase, registering a remarkable 223.3% improvement in energy capacity over the control beams AS and ANS. This considerable augmentation underscores the positive influence of increased fiber volume fraction on the energy-absorbing capability of the beams.

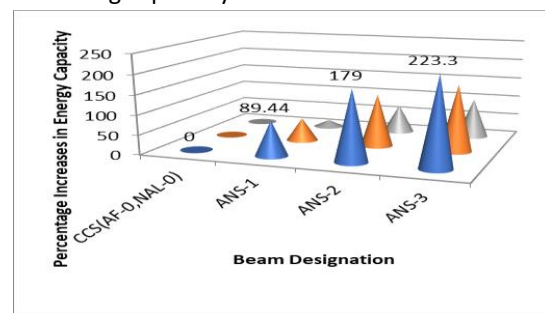


Fig. 9. Effect on Energy Capacity

Conclusions

Based on the outcomes derived from the experiments, the following conclusions can be inferred.

A. Inclusion of steel fibres can enhance the load capacity substantially. The beam ANS3 (with 1% NA, 20% A and 1.5% fibre volume fraction) exhibited a maximum increase of 65.55% in the ultimate load capacity.

B. At various load levels, the fiber-incorporated beams exhibited notable reductions in deflection, with the beam ANS-3 demonstrating a maximum decrease of 88.38%.

C. The steel fibre reinforced ternary blended concrete beams provided ductility indices up to 36.07% in deflection ductility.

D. The energy capacity of the steel fiber-reinforced ternary blended concrete beams exhibited a notable increase of 223.3%, surpassing that of the control beams.

E. The steel fiber-reinforced ternary blended concrete beams underwent flexural failure, characterized by narrower crack widths and reduced crack spacing compared to the control beams.

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