Experimental Investigation on The Strength Behaviour of Conventional and Starcrete Beams Under FRP Retrofitting

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***Abstract*—This research work aimed at an experimental investigation on the load–deflection behavior of conventional concrete beams and starcrete concrete beams before and after retrofitting using Glass Fibre Reinforced Polymer (GFRP) sheets. The objective of the study was to compare the structural performance of conventional concrete beams and starcrete concrete beams and to evaluate the effectiveness of GFRP retrofitting in improving their strength and stiffness characteristics. A total of four reinforced concrete beams with dimensions of 150 mm × 150 mm × 1300 mm were cast and tested under two-point loading conditions to determine their ultimate load carrying capacity, deflection behavior, and crack patterns. After the initial testing, the beams were externally strengthened using GFRP sheets and retested under the same loading conditions. The experimental results indicated that the retrofitted beams exhibited significant improvement in load carrying capacity and reduction in deflection when compared to the un retrofitted beams.**

***Index Terms*—Beam, starcrete, conventional concrete, Retrofitting, GFRP sheet, Epoxy resin, Two-point load, Crack pattern.**

I. INTRODUCTION

Concrete beams are one of the most important structural elements used in buildings and infrastructure due to their ability to resist bending and carry heavy loads. However, conventional reinforced concrete structures often experience deterioration, cracking, and reduction in strength over time because of increased loading conditions, environmental effects, and aging. In recent years, sustainable construction materials and advanced strengthening techniques have gained significant attention in structural engineering. One such sustainable material is starcrete, a starch-based concrete developed using potato starch along with industrial by-products such as fly ash or quarry dust as partial replacement materials. The presence of potato starch acts as a natural binder, while fly ash contributes to the pozzolanic reaction and enhances the strength.

Although Starcrete has shown promising mechanical properties in material-level investigations, its structural behavior under loading conditions and its performance after retrofitting require further study. Retrofitting techniques are widely adopted to strengthen damaged or deficient concrete structures and extend their service life. Among the various strengthening methods, Glass Fibre Reinforced Polymer (GFRP) sheets are commonly used due to their high strength-to-weight ratio, corrosion resistance, ease of application.

In the first phase of this research, an experimental investigation was carried out on conventional concrete and starcrete concrete with 10%, 20%, and 30% partial replacement of cement. Based on the results of compressive strength, split tensile strength, and flexural strength tests, the 20% starcrete replacement was identified as the optimum mix. Therefore, in the present study, reinforced concrete beams were cast using the optimum 20% starcrete mix. An experimental investigation was then conducted to compare the load–deflection behavior, ultimate load-carrying capacity, and crack patterns of conventional concrete and starcrete concrete beams before and after retrofitting using Glass Fibre Reinforced Polymer (GFRP) sheets.

II. LITERATURE REVIEW

1) Dr Aled Roberts, et.al (2023): Researchers from the University of Manchester introduced starcrete, an innovative bio-based construction material developed using simulated Martian regolith, potato starch, and a small quantity of salt as the binding components. Experimental studies reported that starcrete achieved a compressive strength of approximately 72 MPa, which is considerably higher than that of conventional concrete (around 32 MPa) and outperforms many previously developed materials intended for extraterrestrial construction. In addition to its superior mechanical performance, starcrete offers significant environmental benefits by reducing dependence on ordinary Portland cement, whose production is responsible for a substantial share of global carbon dioxide emissions. Owing to its potential for both space exploration and sustainable construction on Earth, efforts have also been initiated to commercialize this material for future engineering applications.

2) Anumol Raju, et.al (2013): reinforced concrete structures gradually lose their structural efficiency due to factors such as reinforcement corrosion, environmental degradation, excessive service loads, and construction deficiencies. Rehabilitation through retrofitting has become a practical and economical solution for restoring the strength and extending the service life of existing structures, thereby avoiding complete replacement. Among the various strengthening techniques, Fibre Reinforced Polymer (FRP) composites have gained widespread acceptance because of their high strength-to-weight ratio, excellent corrosion resistance, durability, and ease of application. The study evaluated the performance of reinforced concrete beams strengthened using different Fibre materials, including carbon Fibre, glass Fibre, steel Fibre, coir Fibre, and polypropylene Fibre. Full-wrap retrofitting was adopted by bonding the FRP sheets to the beam surface with epoxy resin to ensure effective load transfer.

3) P. Ganesh, et.al (2019): Reinforced concrete (RC) beams are essential structural elements that transfer loads from slabs and other structural components to columns and supports. these members may experience deterioration due to factors such as environmental exposure, aging, increased loading, poor construction practices, or structural modifications. To restore or improve the structural performance of such members, strengthening techniques such as repair, retrofitting, and rehabilitation are commonly adopted. Various strengthening techniques have been developed for RC beams, including externally bonded steel plates, concrete jacketing, fibre reinforced polymer (FRP) strengthening, external prestressing, and ultra-high-performance concrete (UHPC) overlays. Among these methods, FRP strengthening has gained significant attention due to its high strength-to-weight ratio, corrosion resistance, and ease of installation. However, traditional techniques such as steel plate bonding and concrete jacketing are still widely used due to their reliability and effectiveness. The selection of an appropriate strengthening method depends on several factors such as structural requirements, cost, durability, and site conditions. understanding the advantages and limitations of these strengthening techniques is essential for selecting an efficient method to improve the performance and service life of beams.

4) Sarath Chandra Kumar, et.al (2011): The influence of fly ash as a partial replacement for cement in concrete and reported significant improvements in both sustainability and material performance. Replacing a portion of cement with fly ash reduces cement consumption, thereby lowering carbon dioxide emissions associated with cement production. Although the inclusion of fly ash slightly prolongs the initial setting time, it facilitates easier mixing, placing, and finishing of concrete. The study also observed that fly ash concrete exhibits relatively lower early-age compressive strength because of the slower pozzolanic reaction. However, continued hydration and pozzolanic activity at later ages contribute to the formation of additional cementitious compounds, resulting in higher long-term strength than conventional concrete. The optimum replacement level was reported to

be 20–30%, where the concrete demonstrated the best balance between strength development and durability.

5) C. Marthong, et.al (2012): The paper investigates how the partial replacement of Ordinary Portland Cement (OPC) with fly ash affects the mechanical and durability properties of concrete. Fly ash, a by-product from thermal power plants, possesses pozzolanic properties due to its silica and alumina content, which react with calcium hydroxide from cement hydration to form additional cementitious compounds. The study used three grades of OPC—33, 43, and 53—and replaced cement with fly ash in proportions of 10%, 20%, 30%, and 40% by weight. Tests were conducted on mortar cubes, concrete cubes, and beams to evaluate compressive strength, shrinkage, and durability under sulphate attack. The results revealed that adding fly ash significantly improves the workability of concrete due to its fine and spherical particles, which act as a lubricant and enhance flowability. However, early-age strength decreases with increasing fly ash content, especially at higher replacement levels (above 30%). This is because the pozzolanic reaction of fly ash is slower compared to cement hydration. Despite this, long-term strength (at 90 days) improved notably, especially for mixes with 20% fly ash, where the strength approached that of conventional concrete.

III. STARCRETE AND CONVENTIONAL MIXES

starcrete is a sustainable bio-based construction material initially developed for infrastructure applications in extraterrestrial environments. Its development was motivated by the need to utilize locally available resources for construction, thereby minimizing the transportation of conventional building materials from Earth. Owing to its favorable mechanical properties and environmentally friendly composition, starcrete has recently gained attention as a sustainable alternative to conventional cement-based materials. as a potential partial replacement for cement in conventional concrete.

The primary binding component of starcrete is potato starch, which functions as a natural polymer binder. When blended with supplementary cementitious materials such as fly ash or quarry dust, the starch forms a cohesive matrix that effectively binds the aggregate particles. A small quantity of salt is commonly incorporated to improve the bonding characteristics of the starch, resulting in enhanced mechanical performance. The combined action of starch and pozzolanic materials produce a denser internal structure.

Conventional concrete primarily relies on Ordinary Portland Cement (OPC) as the binding material, where strength development occurs through the hydration process. Although OPC-based concrete provides satisfactory structural performance and long-term durability, cement manufacturing contributes significantly to global carbon dioxide emissions. Moreover, conventional concrete possesses relatively low tensile strength and exhibits brittle failure under loading.

Replacing a portion of cement with starcrete provides an environmentally sustainable alternative while maintaining the mechanical performance of concrete. The fly ash present in the starcrete mixture participates in pozzolanic reactions with calcium hydroxide released during cement hydration, producing additional calcium silicate hydrate (C–S–H) gel that enhances the concrete matrix. Simultaneously, the starch binder improves particle adhesion and minimizes micro-void formation. Consequently, starcrete-modified concrete offers improved strength characteristics, enhanced durability, and reduced environmental impact compared with conventional concrete.

IV. DIMENSIONS

For the experimental investigation, reinforced concrete beam specimens were cast with standard dimensions of 150 mm × 150 mm × 1300 mm to evaluate their structural behaviour under flexural loading conditions. The beam specimens consisted of both conventional and Starcrete concrete beams. These beams were tested under two-point loading to study their load–deflection behaviour, ultimate load carrying capacity, and crack propagation patterns. After the initial testing, the beams were retrofitted using externally bonded Glass Fibre Reinforced Polymer (GFRP) sheets and retested under the same loadingFibreconditions to assess the improvement in structural performance. The adoption of uniform beam dimensions ensured consistency in the experimental program and enabled accurate comparison between the conventional and Starcrete beam specimens before and after retrofitting.

V. EXPERIMENTAL INVESTIGATION

The experimental investigation comprised the collection of materials required for the preparation of conventional concrete and starcrete beams. Material characterization tests were conducted on cement, fine aggregate, coarse aggregate, fly ash, and potato starch to evaluate their fundamental properties and suitability for beam casting. An M30 grade concrete mix was designed and adopted as the control mix for the conventional concrete beam. For the starcrete beams, cement was partially replaced with starcrete constituents at an optimum replacement level of 20% based on the results obtained from previous stages. A total of four RC beam specimens with dimensions of 150 mm × 150 mm × 1300 mm were cast, consisting of one conventional and three starcrete beams. The specimens were prepared following standard casting procedures. The cured beam specimens were initially tested under two-point loading conditions to evaluate their load–deflection behavior, crack propagation patterns before retrofitting. The damaged beams were strengthened using externally bonded Glass Fibre Reinforced Polymer (GFRP) sheets to improve their structural performance. After retrofitting, the beam specimens were retested under the same loading conditions to assess the improvement in flexural strength and overall structural behavior. The experimental results obtained before and after retrofitting were compared to evaluate the effectiveness of GFRP strengthening on conventional and starcrete concrete beams.

VI. RESULTS

The results section presents the experimental outcomes obtained from the testing of RC beam specimens before and after retrofitting. The beam specimens were evaluated under two-point loading conditions to study their structural behavior, including load–deflection, ultimate load carrying capacity, and crack patterns. The results obtained for conventional and Starcrete beams were compared. After the initial testing, the beam specimens were strengthened using externally bonded GFRP sheets and retested under the same loading conditions. The retrofitted beams exhibited noticeable improvement in strength along with reduced deflection and controlled crack propagation. The experimental results obtained before and after retrofitting were compared and evaluated.

TAB 1: RESULTS OF CONVENTIONAL BEAM(B1)

Load (kN)	Deflection at l/2 (mm)	Deflection at l/3 (mm)	Remarks
0	0	0	
15	0.5	0.2	
28	2.7	0.7	First crack
35	3.3	1.15	
44	4.6	1.4	
50	7	2.3	Ultimate Load

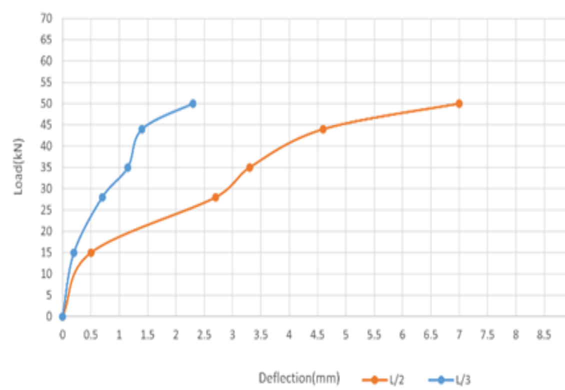


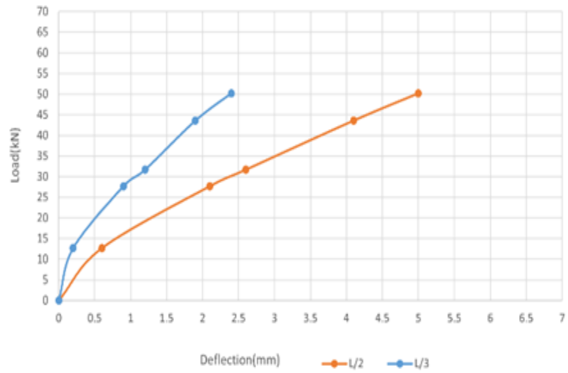
FIG 1: GRAPH RESULTS OF CC BEAM (B1)

The above graph represents the load–deflection behavior of the conventional concrete beam under two-point loading conditions before retrofitting.

TAB 2: RESULTS OF 20% STARCRETE BEAM (B2)

Load (kN)	Deflection at l/2 (mm)	Deflection at l/3 (mm)	Remarks
0	0	0	
12.7	0.6	0.2	
27.7	2.1	0.9	
31.7	2.6	1.2	First crack
43.6	4.1	1.9	
50.2	5	2.4	Ultimate Load

FIG 2: GRAPH RESULTS OF 20% STARCRETE BEAM (B2)

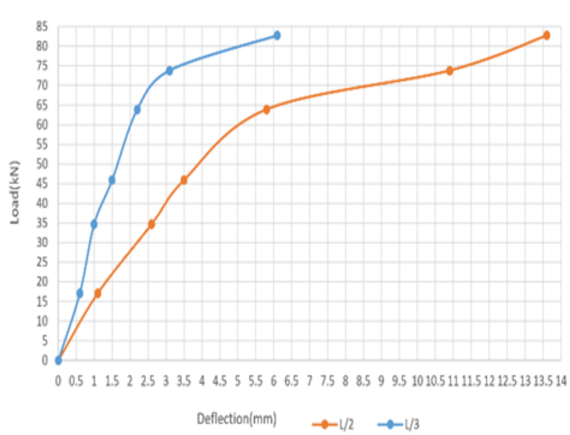


The above graph represents the load–deflection behavior of the 20% starcrete beam under two-point loading conditions before retrofitting.

TAB 3: RESULTS OF 20% STARCRETE BEAM (B3)

Load (kN)	Deflection at l/2 (mm)	Deflection at l/3 (mm)	Remarks
0	0	0	
11.4	1	0.5	
25.6	2.4	1.1	
34.8	3.4	1.6	First crack
45	4.6	2.4	
52	9.9	4.2	Ultimate Load

FIG 3: GRAPH RESULTS OF 20% STARCRETE BEAM (B3)

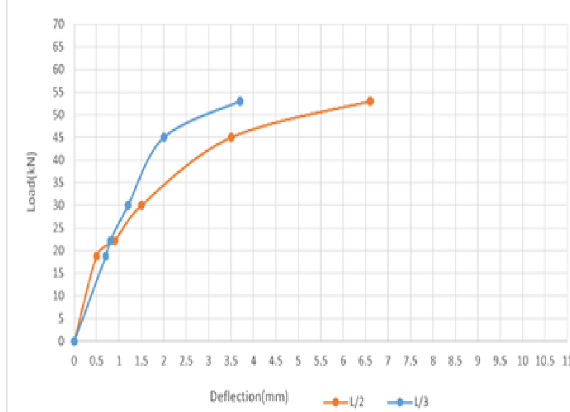


The above graph represents the load–deflection behavior of the 20% starcrete beam under two-point loading conditions before retrofitting.

TAB 4: RESULTS OF 20% STARCRETE BEAM (B4)

Load (kN)	Deflection at l/2 (mm)	Deflection at l/3 (mm)	Remarks
0	0	0	
18.8	0.5	0.7	
22.2	0.9	0.8	
30	1.5	1.2	First crack
45	3.5	2	
53	6.6	0	Ultimate Load

FIG 4: GRAPH RESULTS OF 20% STARCRETE BEAM (B4)

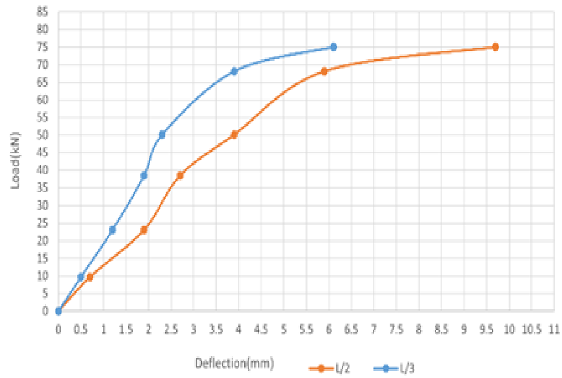


The above graph represents the load–deflection behavior of the 20% starcrete beam under two-point loading conditions before retrofitting

TAB 5: RESULTS OF CONVENTIONAL BEAM RETROFITTED ON 3 SIDES (R1)

Load (kN)	Deflection at l/2 (mm)	Deflection at l/3 (mm)	Remarks
0	0	0	
9.7	0.7	0.5	
23.1	1.9	1.2	
38.5	2.7	1.9	
50.1	3.9	2.3	
68.1	5.9	3.9	
75	9.7	6.1	Ultimate Load

FIG 5: GRAPH RESULTS OF CONVENTIONAL BEAM RETROFITTED ON 3 SIDES (R1)

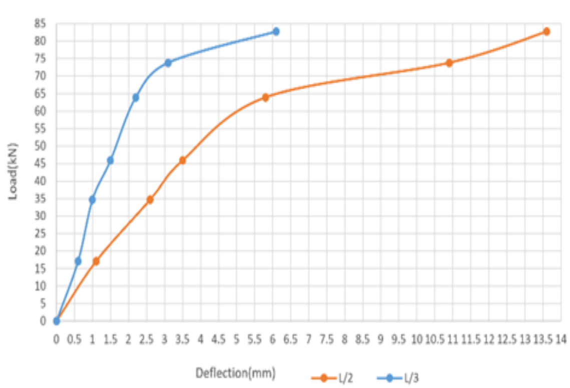


The above graph represents the load–deflection behavior of the 3 side Retrofitted conventional beam under two-point loading conditions.

TAB 6: RESULTS OF STARCRETE BEAM RETROFITTED ON 3 SIDES (R2)

Load (kN)	Deflection at l/2 (mm)	Deflection at l/3 (mm)	Remarks
0	0	0	
17.1	1.1	0.6	
34.7	2.6	1	
45.9	3.5	1.5	
63.9	5.8	2.2	
73.8	10.9	3.1	
82.7	13.6	6.1	Ultimate Load

FIG 6: GRAPH RESULTS OF STARCRETE BEAM RETROFITTED ON 3 SIDES (R2)

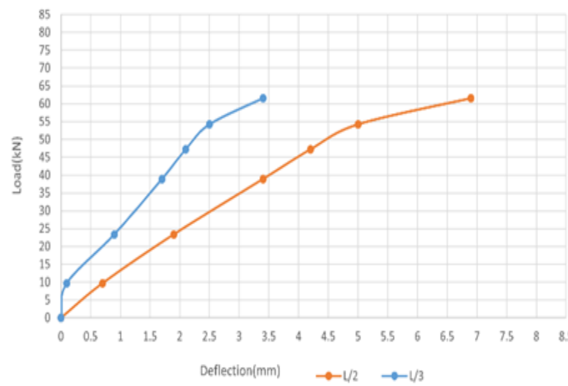


The above graph represents the load–deflection behavior of the 3 side Retrofitted starcrete beam under two-point loading conditions.

TAB 7: RESULTS OF STARCRETE BEAM RETROFITTED ON 4 SIDES (R3)

Load (kN)	Deflection at l/2 (mm)	Deflection at l/3 (mm)	Remarks
0	0	0	
9.7	0.7	0.1	
23.4	1.9	0.9	
38.9	3.4	1.7	
47.2	4.2	2.1	
54.2	5	2.5	
61.5	6.9	3.4	Ultimate Load

FIG 7: GRAPH RESULTS OF STARCRETE BEAM RETROFITTED ON 4 SIDES (R3)



The above graph represents the load–deflection behavior of the 4 side Retrofitted starcrete beam under two-point loading conditions.

CRACK PATTERN AND FAILURE MODE

Crack pattern refers to the distribution, direction, shape, and location of cracks that develop in a structural member when it is subjected to loading. It helps in identifying the type of stresses acting on the structure, such as flexural, shear, or torsional stresses.

FIG 8: FAILURE OF BEAM

FIG 9: CRACK PATTERN OF BEAM

The observed crack is identified as a shear crack due to its diagonal orientation across the beam. Shear cracks typically occur when the shear stress exceeds the shear capacity of concrete, resulting in inclined cracks at about 30°–45° to the beam axis. The crack pattern observed at the ultimate load of 53 kN confirms a shear failure mechanism in the beam.

VII. CONCLUSION

The experimental investigation was conducted to evaluate the structural performance of conventional reinforced concrete beams and beams containing 20% starcrete as a partial replacement for cement before and after GFRP retrofitting. The experimental results showed that the starcrete beams exhibited slightly higher ultimate load capacities than the conventional beam before retrofitting. The conventional beam failed at 50 kN, whereas the starcrete beams achieved ultimate loads ranging from 50.2 kN to 53 kN, demonstrating that the optimum starcrete mix can effectively maintain and slightly improve structural strength. Retrofitting with Glass Fiber Reinforced Polymer (GFRP) sheets significantly enhanced the load-carrying capacity of all beam specimens. The retrofitted conventional beam reached an ultimate load of 75 kN, while the three-side retrofitted starcrete beam achieved the highest ultimate load of 82.7 kN. In contrast, the fully wrapped starcrete beam recorded 61.5 kN, which may be attributed to non-uniform epoxy distribution, bonding deficiencies, fibre alignment, or curing-related issues. These results indicate that three-side GFRP retrofitting is more effective than full wrapping under the experimental conditions adopted in this study.

The study also confirms that epoxy resin provides effective bonding between the concrete surface and GFRP sheets, enabling efficient stress transfer, controlling crack propagation, and delaying beam failure. Since the top surface of the beam is primarily subjected to compression and lies close to the neutral axis, excluding it from wrapping does not significantly reduce flexural performance while making the strengthening process more economical. Overall, the findings demonstrate that starcrete is a promising sustainable alternative to conventional concrete, and when combined with properly executed GFRP retrofitting, it can significantly improve the strength, durability, and structural performance of reinforced concrete beams. This approach provides an effective and environmentally sustainable solution for strengthening existing reinforced concrete structures.

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