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RESEARCH ARTICLE OPEN ACCESS

ANALYSIS OF IMPACT RESISTANCE AND DURABILITY OF REINFORCED CONCRETE SLAB REINFORCED WITH GLASS FIBER REINFORCED POLYMER BARS (GFRP)

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***Abstract*-Glass Fiber Reinforced Polymer (GFRP) bars are a cutting-edge composite material that has garnered substantial interest in the construction sector. In this project, I used glass fiber reinforced polymer bars as an alternative to steel bars. These bars consist of high strength glass fiber encased in a polymer resin, often derived from vinyl ester or polyester. For conventional steel structures, exposure to harsh environment leads to corrosion and ultimately results in loss of serviceability and strength. GFRP demonstrate resistance to chemical degradation and are durable in harsh environments. In this project, the conventional steel reinforcement is replaced with 100% Glass Fiber Reinforced Polymer (GFRP) in one model, and with 50% GFRP in another. A control model with 100% steel reinforcement has also been constructed for comparison. GFRP rebar offer enhanced durability and a higher strength-to-weight ratio, making them a promising alternative. In addition, durability was assessed through water absorption and carbonation tests. The carbonation depth was determined using the phenolphthalein indicator test. The results highlight the potential of GFRP bars as a corrosion-resistant alternative to steel, offering improved long-term durability with comparable structural performance. The mechanical properties like compressive, flexural strengths & impact resistance and durability properties like water absorption & carbonation were studied and compared with conventional concrete. The effects of impact energy, GFRP bar properties, and concrete properties on the RC slab's behavior were also examined.**

***Keywords*-Steel bar, GFRP Bars, Concrete slabs. Impact resistance, Durability test, Impact loading, Water absorption test, Carbonation test.**

I. INTRODUCTION

The GFRP bars are an alternative to steel and glass fiber for reinforced concrete. They are manufactured from vinyl ester and polyester resin. Due to its low cast, and high tensile strength, concrete is a material that is utilized in construction on a large scale. Research shows that the GFRP bars are stronger and more flexible than the steel bars. But research showing the impact strength of the bars is very limited. The impact strength of materials plays a crucial role in the design and safety of critical structures due to the increase in natural and man-made disasters such as earthquake, tsunami, toppling of rocks; the structures are subjected to high velocity shock loads. Though the impact loading on structures is relatively low in day to day life, the structural elements should be against the impact loading to protect the structures.

Chloride-induced corrosion of conventional steel bars is the most common durability problem in reinforced concrete members. Research and field investigations have revealed that GFRP- embedded bars in RC structures warrant satisfactory long-term durability performance in structures, particularly those that are exposed to severe environmental conditions such as seawater. Researchers have studied the impact of loading on reinforced concrete using Charpy's method, defining failure stages such as initial, secondary, and final failure. Several research works have examined the structural performance of concrete beams and their behavior under different conditions. Columns strengthened with fiber polymer under impact loads; there is a gap in research on one-way concrete slabs reinforced with GFRP bars. This paper highlights the importance of investigating the behavior of GFRP- reinforced concrete slabs under impact loading. This paper focuses on the dynamic analysis of concrete slabs reinforced with GFRP bars under impact loading, comparing their behavior to slabs reinforced with traditional steel bars. The study aims to contribute to the understanding of structural behavior under dynamic stresses, such as collisions or earthquakes, and is considered innovative due to the limited research on impact loading in concrete structures.

II. LITERATURE REVIEW

Woman'h et al. (2025) performed experimental work on seawater-mixed GFRP-reinforced RC slabs, evaluating long-term structural performance under flexural loads and durability conditions. Their results contribute to understanding performance degradation in aggressive environments.

Golham and Al-Ahmed (2024) explored the flexural behavior of one-way concrete slabs with openings, reinforced by GFRP bars and strengthened with CFRP sheets. Their experiments showed that using CFRP around openings increased ultimate load capacity by 21–29%, decreased service-load deflection by 35–37%, and enhanced stiffness and load-carrying capacity significantly over strengthened counterparts.

Renbo Zhang et al. (2023) Investigate the impact behavior of Glass FRP (GFRP) reinforced concrete slabs with different impact masses and velocities. Under impact loads, concrete dissipates most of the impact energy. Finally, both the normalized peak and residual displacements of the plates vary almost linearly with respect to the change in their natural frequency.

Abdul Muttalib and Ends (2022) focused on RC slabs subjected to repeated impact loading with high mass and low velocity. They observed that slabs with higher steel reinforcement ratios resisted localized damage more effectively, registering mainly discontinuous hairline cracks at the bottom surface. The failure modes were driven primarily by shear forces resulting from inertial effects.

Salih et al. (2022) Investigate the behavior of unidirectional concrete slabs reinforced with GFRP and plains steel was made. A simple device is made mainly to apply an impact load by applying a load of 7kg falling on center of the plate from two different heights. The result was elongation of GFRP plates is 25% less than steel bar plate, and the span was also 37.5% less.

III. METHODOLOGY

A. Ordinary Portland cement

Ordinary Portland Cement (OPC) 53 grade was mainly used for preparing the specimens. The important properties of cement are given in Table 1.

TABLE 1
PROPERTIES OF CEMENT

S.No	Test Performed	Result
1	Fineness test	3%
2	Consistency test	31%
3	Specific gravity of cement	3.15
4	Initial setting time	54min
5	Final setting time	320min

B. Aggregate

The M- sand confirming to IS: 383 - 1970 is used as the fine aggregate and Coarse aggregate of maximum size 20 mm was used as the coarse aggregate. The properties of fine and coarse aggregates are presented in Table 2 & Table 3.

TABLE 2
PROPERTIES OF FINE AGGREGATE

S.No	Property	Fine Aggregate Value
1	Specific gravity	2.65
2	Fineness test	2.85
3	Density	1650 kg/m3

TABLE 3
PROPERTIES OF COARSE AGGREGATE

S.No	Material	Coarse Aggregate Value
1	Specific gravity	2.72
2	Fineness test	7.2
3.	Density	1720 kg/m3

C. Steel

The size and diameter of reinforcement were selected with references to IS: 1786-1985. The 8 mm and 12 mm diameter bars used have been tested for their tensile stress in a universal testing machine. The properties of steel are given in Table 4.

TABLE 4
PROPERTIES OF STEEL BARS

S.No	Mechanical Properties	Steel bar (8mm)
1	Tensile strength	500
2	Modulus of elasticity	200

D. Glass Fiber Reinforced Polymer bars

Glass fiber reinforced polymer rebar is used as the internal reinforcement in RC slabs. Alternatively, glass fiber-reinforced polymers (GFRP) are considered a promising substitute for reinforcing steel, especially in structures exposed to aggressive environments. GFRP bars consist of continuous fibers, which are responsible for the strength and stiffness of the composite. They are embedded in polymer resin, which is their binding material. GFRP bars are characterized by high strength, low weight, easy handling, low maintenance and high durability even in quite harsh environments. However, the modulus of elasticity of GFRP bars is lower than that of steel bars. Thus, despite the relatively high load-bearing capacity of reinforced plastic reinforced concrete structures. There are four main types of FRP rods: carbon, aramid, glass and basalt. The properties of GFRP rebar are given in Table 5.

TABLE 5
PROPERTIES OF GFRP BARS

S.No	Mechanical Properties	GFRP bar (8mm)
1	Tensile strength	1011
2	Modulus of elasticity	64.8

E. Materials used

For this study, Ordinary Portland Cement (OPC) 53 grade with specific gravity of 3.15 is used for the concrete. M-sand with specific gravity of 2.65 which lies under zone II with fineness modulus of 2.9 as per IS codes is used as fine aggregate. 12.5mm coarse aggregate with a specific gravity of 2.72 is used. For reinforcement purposes, Fe415 steel and GFRP bars are used.

F. Mix proportion

M25 grade of concrete that reaches the characteristic compressive strength of approximately 32MPa is used for the specimens throughout the study. The mix proportion is done using IS: 10262-2019. The proportion of M25 grade of concrete is calculated as 1:1:2. Table 6 shows the mix proportion of materials for $1m^3$ of concrete. Water cement ratio of 0.48 is used for concrete. Design of the mix proportion given in table 6.

TABLE 6

MIX PROPORTION OF CONCRETE FOR 1M^3

Cement	320 Kg/m^3
Water	160 Kg/m^3
Fine aggregate	560 Kg/m^3
Coarse aggregate	840 Kg/m^3

G. Casting & testing of the cube

The compression strength test is carried out on the cube to check whether the target strength of M25grade concrete is achieved. The trial mix concrete cube with the dimension of 150x150x150mm is selected and allows for curing. The test is carried out 7 and 28 days after casting. The compression test of the concrete cube given in Table 7. Fig 1 shown in compression testing in machine.

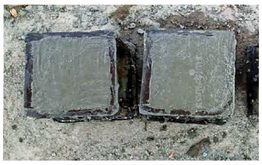


Fig 1 Casting and Compression test on concrete cube

TABLE 7
COMPRESSION TEST ON CUBES

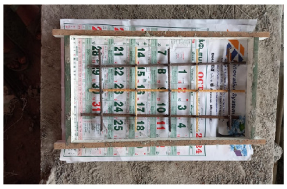
Specimens	Compressive Strength (N/mm^2)	
	7 days	28 days
1	22.35	33.86
2	22.78	33.22
3	23.75	34.45
	Average compressive strength	33.84

H. Mixing, casting and curing

Concrete is mixed with the help of a concrete mixture. Slabs with varying center to center distance bars were cast. Size of the slab specimen used is 600mm × 300mm × 50mm for both cases. The size of the bars used is 8mm. The slabs were cast and left in the laboratory for 24hrs before drying. The slabs are cured for 7 and 28 days before testing. Fig 2 shows that types of reinforced slab and casting of slab.

Steel reinforcement

GFRP reinforcement



Both steel & GFRP reinforcement

Casting of slab

Fig 2 Types of Reinforced slabs

IV. EXPERIMENTAL TESTING AND RESULT

I. Testing of the slab under Impact Loading

The slabs were tested under impact loading conditions. In this method, a heavy weight is lifted to a certain height and then released to fall onto the slab. The experimental setup was placed, and the weight of the load (m) is about 65kg, and the height of fall (h) is taken as 50 cm. The drop weight is raised to a 50cm height above the test specimen. The height is chosen to achieve the desired impact energy. The drop weight is then released, allowing it to fall and impact the test specimen. Then the number of blows was noted. Impact loads can result from various sources and have different effects on the slab, depending on its design, construction, and the magnitude of the impact. From the above tested slabs broken off from the slab. This is one of the failures that caused during the impact loading condition. Based on the observation of field data, especially number of blows and determination of parameters namely energy absorption & crack resistance at ultimate conditions, impact crack resistance ratio and impact residual strength ratio, the performance of conventional slab was compared to GFRP reinforced slabs. One of the major observations carried out in the impact load test on slabs is the number of repeated blows of the drop weight. Table 8 shows the result of conventional, GFRP and Both steel & GFRP reinforced slab under impact loading.

TABLE 8 - RESULT OF CONVENTIONAL, GFRP AND BOTH STEEL & GFRP SLAB UNDER IMPACT LOADING

Name Of the specimens	**Units**	**RC slab**	**GFRP RC slab**	**Both GFRP RC slab**
No of Blows at service Crack (Ns)	-	3	2	4
No of blows at ultimate Crack (Nu)	-	6	5	8
Total length of crack (lc)	mm	14	12	13
Maximum crack width (mm)	mm	3	3	4
Service energy absorption (EAs)	kN.m	8.60	5.74	11.4
Ultimate Energy Absorption (EAv)	kN.m	17.2	14.3	22.9
Service crack resistance (Rs)	MPa	136.5	61.27	168.6

Ultimate crack resistance (Rv)	MPa	63.7	51.0	68.87
Impact crack resistance (Cr)	-	1.88	1.50	2.03
Impact residual Strength (Irs)	-	2	1.82	2.08

Table 8 shows the Test results under impact loading conditions. It is observed that the performance of conventional slab is better than GFRP slab under impact test. The crack pattern involves the failure of concrete at first, and mostly it is seen around the edges of the slab. Due to the high modulus of elasticity, steel bars withstand higher number of blows till impact failure than GFRP. The Conventional slab has good impact resistance due to the toughness of concrete and the reinforcement bars embedded within it. It can withstand a certain degree of impact before showing visible damage, such as cracking.

J. Water Absorption Test

The size of slab used for the water absorption test was 600mm x 300mm x 50mm. The slabs are cured for 28 days. Then the cured slabs are dried at 105^{0}C for 72 hours and cooled down to room temperature in a dry state for one day before being weighted and that was taken as W_1. Next, the cooled specimens were submerged in water for 30 min. After it was weighed and taken as W_2. Water absorption is calculated using the following formula: [Water absorption (%) = (W2 – W1 / W1) X 100]. A comparison is made with water absorption attained by the specimens and discussed below. The table 9 shows the water absorption test result.

TABLE 9

RESULT OF WATER ABSORPTION TEST

SAMPLE	W1 (g)	W2 (g)	Water Absorption (%)
Steel RC Slab	20300	21200	4.43
GFRP RC Slab	19800	20555	3.80
Both steel & GFRP Slab	20000	20820	4.10

K. Carbonation Test

The size of the slab used for the carbonation test was 600mm x 300mm x 50mm. After 28 days of curing, the specimens were exposed to the local environment for another 14 days. After 42 days, the specimens were split into two halves using a compression testing machine. The Phenolphthalein solution was sprayed onto the split surface of the specimen. The specimen will change into a pink color after the application of Phenolphthalein solution. If there are no changes seen in the pink color, it shows the slab is not affected by carbonation. Measure the colorless zone of the slab to determine carbonation depth. Table 10 explains the result of carbonation depth of slabs.

TABLE 10

RESULT OF CARBONATION DEPTH

SAMPLE	Carbonation depth (mm)
Steel RC Slab	10
GFRP RC Slab	5
Both Steel & GFRP RC Slab	6.5

L. Cost Analysis

The fig 3 and fig 4 shows that the price list respectively Glass Fiber Reinforced Polymer Bars (GFRP) and steel bars. Compared to the cost, the GFRP bars were 43% less than steel bars, which is economical.

SHINESTAR
FGC REBARS
Price List

Size	Rate per metre (Excl GST)	Rate per metre (Incl GST)	Sizes Available	MOQ	Lead Time
3mm	₹2.95	₹3.48	12m	12m	3 days
3.5mm	₹4.45	₹5.25	12m	12m	3 days
4.5mm	₹7.40	₹8.73	12m	12m	3 days
6mm	₹8.95	₹10.56	6m, 12m, 100m	6m	1 day
7mm	₹14.20	₹16.76	12m, 100m	6m	3 days
8mm	₹18.90	₹22.30	6m, 12m, 100m	6m	1 day
10mm	₹25.20	₹29.74	6m, 12m, 100m	6m	1 day
12mm	₹37.80	₹44.60	12m, 100m	12m	3 days
16mm	₹76.75	₹90.57	6m	12m	3 days
18mm	₹99.95	₹117.94	6m	2000m	14 days
20mm	₹127.25	₹150.16	6m	12m	3 days
22mm	₹154.50	₹182.31	6m	2000m	21 days
25mm	₹185.50	₹218.90	6m	2000m	21 days
32mm	₹322.50	₹380.55	6m	2000m	21 days

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Fig 3 Price List of GFRP bar

Brand	Size	Price (₹/tonne)	Price (₹/kg)
TATA Tiscon	8mm	74,000	74
JSW	8mm	73,000	73
SAIL	8mm	72,000	72
Vizag	8mm	72,000	72
Meenakshi	8mm	63,000	63
Kamdhenu	8mm	64,500	64.5
Primegold	8mm	64,500	64.5
A1 Gold	8mm	64,000	64

Fig 4 Price List of Steel bars

CONCLUSION

1. RC slabs were cast using steel and GFRP bars to study behavior under impact loading and durability.
2. GFRP bars are **43%** cheaper than steel bars, offering an **economical** option.
3. Under **"Impact loading condition",** the Conventional slab had **25.33%** higher impact resistance than the GFRP slab. The Steel & GFRP slab had **7.98%** higher resistance than the conventional slab.

4. From the durability test **"Water absorption at 28 days"** all type of slab showed water absorption values below 5%, which is typically considered acceptable.
5. From the durability test **"Carbonation test",** GFRP slab had less carbonation depth while compare other type of slabs.
6. GFRP RC slabs show the best durability underwater and carbonation exposure; Steel RC slabs have higher corrosion risk due to carbonation.
7. Both Steel & GFRP reinforced slabs offer a compromise between strength and Durability.

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