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An Experimental study on bond strength of GFRP rebars with Polypropylene fibres

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Abstract: Failure of steel structure due to their corrosion, fatigue and its affinity towards electromagnetism have given rise in usage of substances such as standard corrosion inhibitors, mostly made of heavy metals which are threat to environment and steel reinforcement. While green corrosion inhibitors on other hand possess difficulty in extraction and storage have given rise to quest among engineers to fetch a reinforcement that meet expectations. In last decades the Fibre Reinforced Polymer (FRP) rebars have turned to be eminent because of its resistance to corrosion, electromagnetism. The Glass Fibre Reinforced Polymer (GFRP) rebars among the other FRP's are more preferable due to their stability, durability. In this paper bond performance of GFRP rebars incorporated with polypropylene fibres is experimentally investigated and is compared to traditional steel rebars. Total 12 beams specimens were casted with half of them reinforced with steel rebars and rest with GFRP rebars and polypropylene fibres. Using M20 grade of concrete, steel rebars of 6mm, 8mm ,10 mm and GFRP rebars of 6mm, 10 mm were used, to cast beam specimens of dimension 500 mm × 100 mm × 100 mm with developmental lengths of 5d, 7d, 10d and a clear cover of 25 mm. Single point load test was performed on completion of 28 days of curing. Peak load, Ultimate load, bond strength, bond stress was determined for the following beam specimens.

Key words: Bond behaviour, GFRP rebars, Polypropylene fibres, Single point load test.

INTRODUCTION

After the Industrial revolution and urbanisation, cement concrete has become most ubiquitous engineering construction material because of its versatile properties namely high compressive strength, fire resistant properties and great adaptability. Concrete is now ranked as second most used material in construction after water [1]. Concrete, although strong in compression is weak in tension, shear and flexure creates a need for reinforcement. Steel on other side has high tensile strength, high strength to weight ratio and its coefficient of thermal expansion being almost equal to that of concrete makes it as a suitable a reinforcement for concrete [2]-[4]. Steel due to its metallic nature is susceptible to corrosion, electromagnetism and fatigue. Therefore, steel rebar upon time and excessive loading can undergo yielding and fatigue.[5]-[7]

Various offshore structures, bridges, under sea installations hold great impact over country's economy and industrial development [8][9]. While evaluating the overall performance of existing offshore structures, corrosion is listed as most common threat, causing structural degradation [10][11]. The marine environment possessing factors like dissolved oxygen, temperature, salinity, pH causing corrosion and is proven to be faster in offensive setting [12]-[14]. It is reported that losses worth 110 billion USD is faced by India in various sectors due to corrosion [15] and contributing about 5-7 % of India's Gross Domestic Product (GDP) [15] and with an economy goal of 5 trillion USD, challenges dealing with losses and maintenance plays a vital role [17]. This has led to alterative solutions such as use of corrosion inhibitors, epoxy coatings [18]. Many of them contain heavy metals have adverse effect on atmosphere [19] while green corrosion inhibitors struggle with storage, extraction and on the other toxicity of green corrosion inhibitors is not much explored [20].

Therefore, it has brought a quest among engineers to come up with a suitable reinforcement that meet all the needs. In last decades the Fibre Reinforced Polymer (FRP) rebars have gained attention due to its outstanding resistance to corrosion, electromagnetic neutrality and ease of handling [21].

The fibre reinforced polymer (FRP) bars are made by combining fibres with resin matrix, these fibres are responsible for high alkali resistance and are known for high tensile strength. Unlike, steel FRP rebars are non-homogenous, anisotropic exhibiting

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linear elastic behaviour until rupture. Based on the fibres and resin matrix the rebars can be classified as GLASS FIBRE REINFORCED POLYMER BARS (GFRP), BASALT FIBRE REINFORCED POLYMER (BFRP), ARAMID FIBRE REINFORCED POLYMER (AFRP), CARBON REINFORCED POLYMER (CFRP). The properties of these rebars depend upon the volume of fibres, direction and orientation of fibres and percentage of resin matrix and makes the FRP's much lighter than steel. The density of the rebars varies depending upon the type of fibre, the highest density being of BFRP rebars while lowest being of AFRP rebars, GFRP rebars being more cost-efficient than CFRP and more durable than BFRP rebars therefore more preferable among others [22][23][24]. It is proven that GFRP rebars have shear strength 41 % more than steel and tensile strength about 50 % more than that of traditional steel. A cost comparison disclosed that a water tank constructed underground is about 30.82 % more cost efficient than traditional steel [25]. Although, composite materials have advantages as well as challenges. GFRP rebars have to be prefabricated and cannot be altered on site due to their poor elongation index. GFRP rebars may sound promising but have low toughness and are brittle in nature. This can be dealt by incorporating micro fibres such as polypropylene fibres [26][27]. In this research the bond performance of GFRP rebars with polypropylene fibres is investigated by varying developmental lengths and diameter and their relation with bond strength, bond stress is examined.

2. EXPERIMENTAL PROGRAM

2.1. Materials

- Cement: Ordinary Portland Cement (OPC) 53 grade of specific gravity 3.12 as per IS 8112: 2013 was used.
- Coarse Aggregate: Coarse aggregate passing sieve of 20 mm size and of specific gravity 2.60 as per IS 383-1970 was used.
- Fine aggregate: Fine aggregate of sieve passing 4.75 mm size and of specific gravity 2.65 as per IS 383-1970 was used.

- Polypropylene fibres (PP): Polypropylene fibres of length 20 mm were used. The parameters of polypropylene are illustrated in Table 1. The Figure 1 demonstrates polypropylene fibres used in the research

Figure.1 Polypropylene fibres

Parameter	Performance
Modulus of elasticity	4.14 Gpa
Unit weight	9.1 KN/m^3
Tensile strength	379.2Mpa
Shear strength	170 Mpa
Elongation at breakage	25 %

Table.1 Properties of polypropylene

Glass Fiber Reinforced Polymer (GFRP) rebars: The gfrp rebars of diameter 8 mm and 10 mm were used. They were procured from , Hyderabad. The GFRP rebars used in the research are demonstrated in Fig 2 and their properties are tabulated in table 2

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Figure 2. GFRP rebars

Parameter	Performance
Modulus of elasticity Density Tensile strength Weight Shear strength Bond strength Elongation	56.5 Gpa 1900 kg/m^3 825 Mpa ϕ 10 = 1.8 kg ϕ 8 = 1.14 kg 170 Mpa 12.5 Mpa 4 %

Table 2. Properties of GFRP rebars

Steel rebars: Steel rebars of grade Fe415 were used of diameter 6 mm, 8 mm and 10 mm, the following table 3 illustrates properties of the steel rebars.

Parameter	Performance
Modulus of elasticity Density Tensile strength Weight Shear strength Elongation	221.3 Gpa 7850 kg/m^3 793.0 Mpa ϕ 10 = 2.35 kg ϕ 8 = 1.50 kg ϕ 6 = 0.84 kg 145 Mpa 63 %

Table.3 Properties of steel

2.2. Specimen preparation

Total 12 specimens were created 6 of them were reinforced with steel rebars of varying developmental length 5d,7d and 10d while other 6 beam specimens were reinforced with gfrp rebars incorporated with polypropylene fibres respectively with varying developmental lengths. Mix design of M20 was adopted as in table 4 , polypropylene fibres were added by replacing 2 % of volume of concrete.

Material	Concrete reinforced with P.P fibres	Concrete reinforced without P.P fibres
Cement	345 kg/m^3	345 kg/m^3
Fine aggregates	750 kg/m^3	579.7 kg/m^3
Coarse aggregate	1170 kg/m^3	1136 kg/m^3
Water	190 lr/m^3	190 lr/m^3
Polypropylene fibres	_	2 % of weight of concrete
w/c ration	0.55	0.55

Table 4. Mix proportion for concrete with polypropylene fibre and without polypropylene fibre.

The mould size of 500 mm × 100 mm × 100 mm were chosen as shown below in figure 3 , they were properly cleaned and greased as in figure 4 for easy ejection of beam followed by weighing of materials , manual mixing was adopted in which first materials were dry mixed uniformly and then optimum amount of water was added as per the mix deign to avoid lumps in mix and to ensure uniform mixing and was poured into mould manually as in figure 5 and details of reinforcement are tabulated in table 5 and 6 . After pouring the mix was tamped to avoid air gaps in the mould. The beam specimens were kept for curing for 28 days as shown in figure 6.

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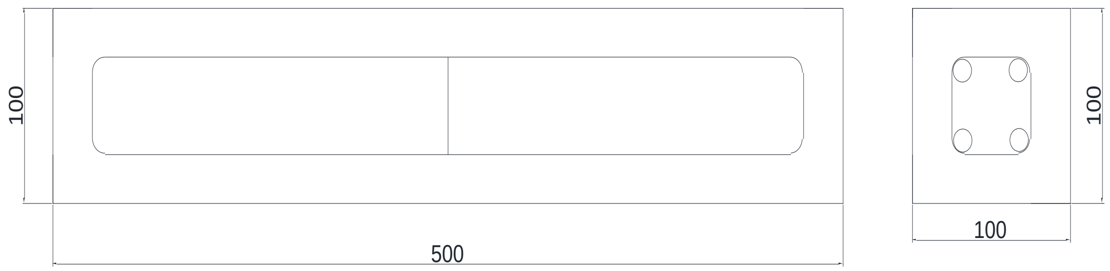

Figure 3. Beam specimen

Figure 4. Greasing of moulds specimens

Figure 5. Casting of beam specimens

Figure 6. Curing of beam

BAR DIAMETER (mm)	DEVLOPEMENTAL LENGTH (Ld)	NO. OF STEEL BARS IN TOP (COMPRESSION ZONE)	NO. OF STEEL BARS IN BOTTOM (TENSION ZONE)	TOTAL BARS	SPACING BETWEEN STIRRUPS (mm)
8 mm	10 D	2	2	4	100 mm c/c
	7D	2	2	4	100 mm c/c
	5D	2	2	4	100 mm c/c
10 mm	10 D	2	2	4	100 mm c/c
	7 D	2	2	4	100 mm c/c
	5 D	2	2	4	100 mm c/c

BAR DIAMETER (mm)	DEVLOPEMENTAL LENGTH (Ld)	NO. OF GFRP BARS IN TOP (COMPRESSION ZONE)	NO. OF GFRP BARS IN BOTTOM (TENSION ZONE)	TOTAL BARS	SPACING BETWEEN STIRRUPS (mm)
8 mm	10 D	2	2	4	100 mm c/c
	7D	2	2	4	100 mm c/c
	5D	2	2	4	100 mm c/c
10 mm	10 D	2	2	4	100 mm c/c
	7 D	2	2	4	100 mm c/c
	5 D	2	2	4	100 mm c/c

3.Results and Discussion

A single point load test is conducted for the beam specimens reinforced with GFRP bar and steel bars as shown in figure 6. To compare the strength characteristic of both the concrete beam specimens they were cured in water for 28 days. The beams were placed horizontally as demonstrated in figure, as demonstrated in figure the beam is kept such that it is pinpointed on its centre of gravity. The load was applied gradually till the concrete beam specimen fails and the following peak loads were noted as depicted in figure 8. Figure 9 and 10 illustrates comparison of bond strengths of steel and GFRP rebars of diameter 8 mm and 10 mm with developmental lengths of 5d 7d and 10d.

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Figure 6. Testing of beam specimens

Figure 7. Single point load testing machine

Figure 8.

REBAR	DIAMETER	DEVLOPEMENTAL LENGTH.	Performance of GFRP rebars		Performance of steel rebars	
			PEAK LOAD AT FAILURE	FLEXURAL STRENGTH	PEAK LOAD AT F A I L U R E	FLEXURAL STRENGTH
1	10 mm	10 d = 100 mm	76.65 KN	15.580 mpa	92.80 KN	18.78 mpa
2		7d = 70 mm	65.25 KN	12.627mpa	70.69 KN	14.314 mpa
3		5d = 50 mm	60.70 KN	12.217 mpa	66.61 KN	13.488 mpa
1	8 mm	10 d = 80 mm	66.80 KN	13.527 mpa	61.46 KN	12.445 mpa
2		7d = 56 mm	62.70 KN	12.696 mpa	56.46 KN	11.433 mpa
3		5d = 40 mm	52.90 KN	10.712 mpa	41.90 KN	8.4 mpa

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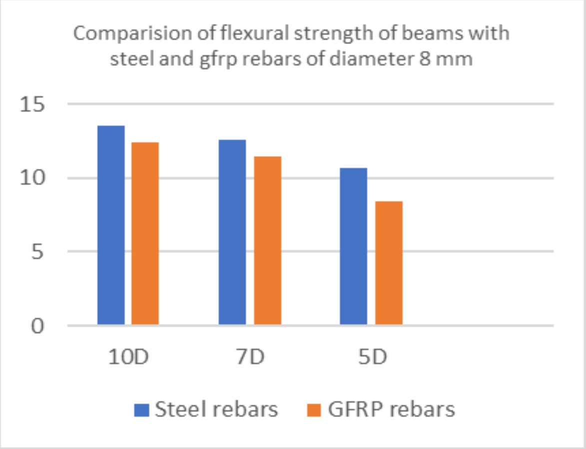

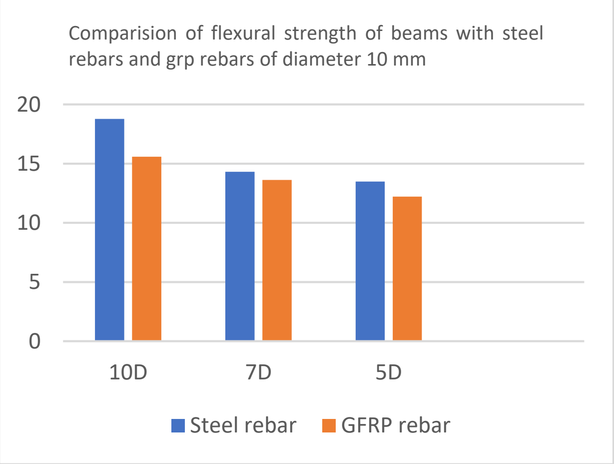

References

[1] MIT, retrieved from https://sustainability.mit.edu/

[2] William E etal, Mechanical properties of steel, Federal Building and Fire Safety Investigation of the world trade centre disaster.

[3] Mechanical Properties of Steel-Reinforced Concrete" (Construction and Building Materials, 2022) - DOI: 10.1016/j.conbuildmat.2022.127323

[4] Steel-Concrete Bond Strength" (Journal of the Structural Division, ASCE, 1973) - DOI: 10.1061/JSDEA4.0001044

[5] Steel Reinforcement Corrosion in Concrete" (Cement and Concrete Research, 2022) - DOI: 10.1016/j.cemconres.2022.103934

[6] Akib Jabed, Md Mahamud Hasan, "Corrosion of Steel Rebar in Concrete" (2023) DOI:10.14773/cst.2023.22.4.273

[7] J. Sanchez Corrosion-induced brittle failure in reinforcing steel (2017); https://doi.org/10.1016/j.tafmec.2017.08.006

[8] Muhammad Wasim Failure analysis of structural steel subjected to long term exposure of hydrogen (2020) https://doi.org/10.1016/j.engfailanal.2020.104606Get rights and content

[9] Yingxin Cui; The Social, Economic, and Political Impacts of Offshore Outsourcing on the Companies and Developing Countries (2022) ; BCP business and management

[10] Dongqin Li, The impact of marine industrial structure rationalization on marine economic growth (2023)

[11] Ruilin Xia, Chen Jia, Yordan Garbatov; Deterioration of marine offshore structures and subsea installations subjected to severely corrosive environment (2024) https://doi.org/10.1002/maco.202314050

[12] Imran Mir Chohan; Effect of seawater salinity, pH, and temperature on external corrosion behaviour and microhardness of offshore oil and gas pipeline: RSM modelling and optimization.

[13] FranK Byron, Corrosion Impact of Offshore Platforms, Structures, and Vessels (2020)

[14] Carlos Guedes Soares; Effect of environmental factors on steel plate corrosion under marine immersion conditions (2011) DOI: 10.1179/147842209X12559428167841

 DOI : 10.35291/2454-9150.2024.0401

[15] ISSDA retrieved from https://m.economictimes.com/industry/indl-goods/svs/steel/corrosion-leads-to-losses-worth-usd-110-billion-in-india-annually-issda/articleshow/102418409.cms

[16] PTI , retrieved from https://timesofindia.indiatimes.com/india-loses-5-7-of-gdp-due-to-corrosion-international-zinc-association/articleshow/83366817.cms

[18] Jilna Jomy, Inhibitors Incorporated into Water-Based Epoxy Coatings on Metals for Corrosion Protection, Journal of Bio- and Tribo-Corrosion (2022) 8:44 https://doi.org/10.1007/s40735-022-00643-7

[19] S.A. Amadi, Impact of corrosion inhibitors on the environment January (2007)

[20] Vishal Varshney, A review paper on green corrosion and its inhibitors, International Journal of Materials Science 2023; 4(1): 27-31.

[21] S Baliram, Characterization of GFRP Material, Volume 6 Issue 3 ISSN: 2457-0826.

[22] Kinga Brózda, ANALYSIS OF PROPERTIES OF THE FRP REBAR TO CONCRETE STRUCTURES, Vol. 2, No. 1, 6-10 (2017), Applied Engineering Letters

[23] Shahad Abdul Adheem Jabbar, Replacement of steel rebars by GFRP rebars in the concrete structures, https://doi.org/10.1016/j.kijoms.2018.02.002

[24] Jianwei Tu, Prediction of the Long-Term Performance and Durability of GFRP Bars under the Combined Effect of a Sustained Load and Severe Environments (2020), MDPI; doi:10.3390/ma13102341

[25] Pratik Patil, GFRP Rebars in Reinforced Concrete Underground Water Tank: A Sustainable and Economical Alternative, DOI: https://doi.org/10.5281/zenodo.7974301(2023)

[26] Ali Akbar Ramezanianpour, Laboratory study on the effect of polypropylene fibre on durability, and physical and mechanical characteristic of concrete for application in sleeper (2013), http://dx.doi.org/10.1016/j.conbuildmat.2013.02.076

[27] Ehab. Ahmed, Bond Stress-Slip Relationship and Development Length of FRP Bars Embedded in Concrete (2008), https://www.researchgate.net/publication/258835428

