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RESPONSE OF CONCRETE BEAM WITH GFRP REBAR TO CORROSION

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Abstract: ***As steel bars are proved to be corrosive, GFRP reinforcement bars are used. The performance of concrete durability is the ability of concrete to resist weathering action, chemical attack, resistance to freezing and thawing and abrasion while maintaining its desired engineering properties. Different concrete requires different degrees of durability depending on the exposure environment properties. This study is to investigate the durability response of concrete beam with GFRP rebar to corrosion. Durability performance of GFRP bars is its longer life span, corrosion resistance, tensile strength, non-conductive to heat and electricity, and high fatigue resistance endurance, impact resistance.***

Keywords: GFRP, Durability, Corrosion, Beam, Steel reinforcement

1. INTRODUCTION

For several years, concrete structures have been regarded as permanent structures with their major advantages being considerable compressive strength, low maintenance and availability. However, it has been observed that many concrete structures are suffering deterioration for some reasons like corrosion. as a porous material, concrete allows fluids such as water, salt and de-icing chemicals to penetrate the concrete and attack the steel reinforcement. Corrosion of the steel reinforcement causes the steel to expand. The bond between the concrete and steel losses and the reinforcement becomes ineffective. GFRP is gaining more popularity in construction of bridges, because bridge deck slabs are one of the most severely affected components in reinforced concrete structures. Since the material offer unique combination of high strength to weight ratio and stiffness to weight ratio, corrosion and fatigue resistance, improved long-term performance to environmental effects, lower maintenance cost, longer service life, lower life cycle cost, it makes them attractive for use in the construction of new slabs and retrofitting and rehabilitation of existing slab panels.

Properly reinforced GFRP concrete slabs exposed to heavy fatigue loads will have less cracking and are projected to last up to 20 times longer than similar structures reinforced with conventional black steel. The prime reason of using GFRP is for concrete longevity.

1.1 GFRP rebar

Corrosion of internal reinforcing steel is one of the chief crosses of failure of concrete structure. Inevitably concrete will crack, creating a great avenue for chlorides to begin oxidizing the steel bar. Fibre reinforced polymers (FRP's) are a proven and successful alternative reinforcing that will give structures a longer service life. A complete spectrum of authoritative consensus design guides, test methods, material and constructions standards, Product procurement specification and qualification procedure are available to the designer and owner to safely and commercially implement FRP's in many different types of structure.

1.2 GFRP characteristics and behaviors

The mechanical properties and behaviors of fibre reinforced polymers (FRP) versus steel reinforcing should be understood prior to undertaking the design of structures using these reinforcements.

FRP systems are increasingly acceptable, Alternative to steel reinforcement for reinforced concrete structures including caste-in-place and pre-and post-tensioned bridges, precast concrete pipes columns, Beams and other components.

Masonry structures also benefits with FRP reinforcement. FRPs using glass fibres are the predominant reinforcing fibres in alkali FRPs. E-glass is the most commonly used fibres. It has high electrical insulating properties, Good heat resistance, and has the lowest cost. S-glass fibres have higher heat resistance and about one-third higher tensile strength than E-glass. The specialty A-glass fibres are resistance to the alkaline environment found in concrete but have higher cost.

2. Review of literature

Masmoudiet al (2003) tested two series 1 and 2 of GFRP bars 12.7 mm diameter were exposed to two different environments, namely the alkaline solution and de-ionized water. Also bars were subjected to sustained tensile loads varying from 20 to 29% of the short-term ultimate tensile strength. Both series specimens were exposed for 104 days (15 weeks) duration. A 13 to 15% reduction for tensile strength in average is observed for both series tests 1 and 2 after 104 days' exposure. It can be noted that residual tensile strengths for conditioned specimens is still in the magnitude range of the specified guaranteed ultimate tensile (94 to 96%) and is higher (135 to 138%) than the specified design strength as recommended by ACI 440 guide lines. It is concluded that the durability performance of the 12.7mm GFRP bars is very good, taking into account the relatively very aggressive environmental conditions being used.

Francesca Ceroni et al (2006) describes resulted in weakness of FRPs to environmental agents (water, alkali, salt solution) or conditions (temperature) is related to penetration or degradation of resin, that protect fibres and allow their collaboration by bond. The "endurance limit", i.e. the reduction of tensile strength under sustained load, which may be as a high as 50%, is a long term effect of fibres. Creep, relaxation and fatigue in RC elements cause effects less relevant than steel reinforcement. The most important FRP concrete mechanisms are due to bond and thermal actions, that govern cracking behaviour and in consequence the strength and stiffness of the element. The transversal coefficient of thermal expansion is 5-8 times the concrete one, inducing high tensile radial stress or reducing bond efficient. As a consequence, Minimum values of concrete cover need to be adapted to prevent splitting failure.

Tarek H. Almusallam et al (2006) concluded that there is significant loss in tensile strength of GFRP bars when subjected to sustained stress for the considered exposure conditions. The results shows that the significant losses (27-29% after 4 months,37-47% after 8 months and 47-55% after 16months) in the tensile strength of GFRP bars when subjected to sustained stress of about 20 to 25% of their ultimate for the 3 environments considered in this study. The loss in tensile strength of the unstressed specimens under the same environments ranges between 2 and 10% after 4 months,13 and 17% for 8 months 16 and 22% for 16 months of exposure

Tarek H. Almusallam et al (2007), discussed results of testing concrete beam reinforced with GFRP bars and subjected to the stress level of about 20 to 22% of the ultimate stress of the GFRP bars. Reference beams were loaded in the temperature control laboratory (24+_3C). Other test beams were either completely or partially immersed in different environment (tap-water and sea-water) at elevated temperature(40+_2C) to the accelerate the reaction. The result shows that the creep effect due to sustain loads was significant for all environments consider in the studies and the highest effect was on beams subjected to wet/dry cycle of sea water at 40+_2C. The creep effect due to loading and environmental exposure was high especially on the concrete strain. The beam mid span deflection, strain in GFRP bars and strain in concrete due to creep where highest in beams placed in sea water at 40+- 2C with wet/dry cycles. GFRP bars at service load should not be exceed 48% of the ultimate strain for normal indoor elements (room temperature), 32% for the structures continuously exposed to non-saline water, 22%for structure exposed to sea water, and 30% for structures in splash zone near the coastal areas.

Jong Pil Won et al (2008), clarified from SEM analysis how the micro structural degradation of GFRP rebar was caused by the increase in the pores, which resulted in polymer matrix de lamination, cracks and a reduction in the cross sectional area of the glass fibers; this contributed to the reduction in the mechanical performance of GFRP rebar. GFRP rebar immersed in tap water for 100 days was 0.2061cc/g, which was negligible compared to exposure to an alkaline environment; the degradation appeared minimal.

LI.torres et al (2009), investigated the short term flexural behavior by varying the reinforcement ratio and the effective depth-to-height ratio. The reinforcing bars had a relatively high modulus of elasticity and different reinforcement amounts and effective depth-to-height ratios were used. All the specimens behaved in a linear way until cracking and due to lack of plasticity in the reinforcement, almost linearly between cracking and failure, with a greatly reduced slope. However, failure took place at relatively large displacements.

Job Thomas et al (2010), discuss the flexure – shear analysis of concrete beams reinforced with GFRP rebar. Effect of FRP reinforcement in the transverse direction on the shear strength of reinforced concrete beam is significant. The increase in shear strength of beam with increase in concrete strength is limited. The a/d ratio corresponding to change mode of failure increases with increase in longitudinal or transverse FRP reinforcement. The prediction shows that the longitudinally FRP reinforced concrete beams having no stirrups fail in the shear for a/d ratio less than 9.0

Juliana Alves et al (2011), showed from test results that fatigue load cycles resulted in approximately 50% loss in the bond strength of sand coated GFRP bars to concrete, while freeze thaw cycles enhanced their bond to concrete by approximately 40%. Larger concrete covers where found more important in cases of larger bar sizes simultaneously subjected to fatigue load and freeze thaw cycles. It seems that a concrete clear cover of 2.0d is an optimum for sand coated GFRP bars.

Radhouane Masmoudi et al (2011), concluded from result that the reduction in the bond strength depends on the transverse coefficients of thermal expansions. For temperature up to 60ºC applied for periods of 4 and 8 months, the average bond strength did not show any significant reduction. For the 80ºC temperature, the maximum reduction after 8 months of ageing in dry environment where 10% and 14% respectively for the 8mm and 16mm GFRP bars, compared to the reference results at 20ºC.

Abdeldjelil Belrbi et al (2012) concluded from test results indicated that ultimate and design bond strength experienced noticeable degradation when exposed to combined environmental conditioning, including freeze thaw cycle, high temperature (60 °C), and de-icing salt solution. Test results showed that bond durability significantly improved owing to the restriction of the concrete crack by the addition of polypropylene fibers. The larger specimens with thicker concrete cover and relatively smaller direct exposed area to the solution of sodium chloride(NaCl) showed better bond durability. Comparing glass FRP specimen with carbon FRP specimens, it was found that bond degradation was tightly correlated to the degradation of FRP bars

Valter Carvelli et al (2013) shows that the ultimate load of the specimens made with lapped GFRP rebar decreases to 40% after 550°C heating because of rebar de bonding. The main conclusion is that the localized heating temperature generates damage in concrete and partial de bonding of the GFRP rebar without causing collapse of the element. The most significant reduction of the load carrying capacity is due to the reinforcement geometry in the overlapping areas.

Chan Gi Park et al (2013), tested and concluded that the GFRP rebar exhibited significant performance degradation to 50-60% of its initial bond strength following a 50-day exposure in 3% NaCl solution to 60°C. The hybrid FRP rebars showed excellent residual bond strength following exposure to NaCl, Na_2SO_4 and $CaCl_2$ environments, indicating no great effects under such conditions. Repeated dry/wet and freeze/thaw cycles had minimal effect on the hybrid FRP re bars, as indicated by residual bond strength of approximately 80%.

Mathieu Robert et al (2013), presented the mechanical, TH durability, and micro structural characterization of unstressed glass-fiber-reinforced polymer(GFRP) reinforcing bars exposed to concrete environment and saline solution under accelerating conditions. The tensile strength retention of the tested GFRP bar would still being 70% and 75% for mean annual temperatures of 50C (the mean annual temperature and marine environment of middle East and war region) and 10C (mean average temperature of the northern region) respectively which is higher than the design tensile strength according to the ACI440.1R It resulted that the change in tensile strength of the tested GFRP bars was minor even at high temperatures(50ºC and 70ºC) making for a more aggressive environment (concrete and saline solution).No significant micro structural changes where observed after 365 days of immersion of the GFRP bars embedded in concrete in the saline solution at 50ºC.

Huanzi Wang et al (2013), indicates from test results that the ultimate flexural strength and ductility experienced minor reduction when exposed to combined environmental conditioning, including freeze thaw cycles, high temperatures (60 °C) and de-icing salt solution. The degradation of concrete may be the main reason for the flexural strength degradation. The addition of fibers with the volume fraction of 0.5% improved the flexural behavior by increasing the ductility level by more than 30%, when compared to the companion beam, for both un-weathered and weathered beams. By improving the concrete properties, adding fibers with a volume fraction of 0.5% has been proved to be an effective way to enhance the ductility of FRP reinforced system. When compared to the companion plain concrete beams, the FRC beams showed more than 30% increase in the ductility index for both un-weathered and weathered beams.

Yousef A. Al-Salloum et al (2013), showed from test result that at 50°C the tap and alkaline solution had the maximum harmful effect on the tensile strength of the tested GFRP bars. Regardless the type or period of exposure all tested GFRP bars had the same mode of failure and had almost linear stress-strain relationship up to failure. The maximum loss in the tensile strength of the tested GFRP bars was observed in the bars exposed to TW50 and ALK50 environments where the average loss was about 24.48% and 24.05%, respectively, of the initial strength after 18 months of exposure. GFRP bars tested in this study had better residual tensile strengths in water and alkaline solution compared to most of the GFRP bars. Almost no losses observed in the tensile module less of elasticity of tested GFRP bras regardless of environmental exposure and exposure period. The SEM results showed that the matrix around the glass fibers in the both ALK50 and TW50 specimens were significantly deteriorate.

Sangeetha Raj et al (2014), shows that glass wrapped specimens exhibited lower corrosion than the carbon wrapped specimens. Resistance to corrosion increases enormously with wrapping. Glass seemed to have impeded the corrosion more than the carbon fibres. This may be due to higher electrical resistance of glass fibre. Epoxy is important in corrosion resistance. Performance increases when number of FRP layers increases.

Ali S. Shanour et al(2014), conducted an experimental study consist of casting and testing of RC beam of size 120*300*2800mm with concrete mix design for M25 grade concrete. A total of seven beams were caste and tested up to failure under four-point bending. The specimens were tested under four-point bending, with 2500mm effective span, and 1100mm shear span, the distance between loads being 300mm. The GFRP ripped bar of 12mm diameter and double sets of plastic mold. Increasing the concrete compressive strength in the order of 25mpa to 45mpa exhibit reducing in the crack width by 52%. Increase ratio of 1.63. The maximum concrete compressive strain cu was recorded between 0.29% and 0.66%. The recorded tensile reinforcement strain for GFRP bars reached the range of 0.012 to 0.0177; these strains corresponded to about 60% to 90% of the estimated ultimate strains of the GFRP bars obtained from the tensile test.

Saraswathy et al (2014), conducted an experimental investigation consists of casting and testing RC beam of size 100×100×500mm with concrete mix design for M20 grade concrete. In one beam made with control specimens of 12mm diameter Fe415 bar in tension zone and 10mm diameter bar in compression zone. The second beam made with 12mm diameter GFRP bar in tension zone and 10mm diameter Fe415 in compression zone. Third beam made with 12mm diameter Fe415 in tension zone and 10mm diameter GFRP bar in compression zone. Fourth beam made with 12mm diameter GFRP bar in tension zone and 10mm diameter GFRP in compression zone. Steel bars were used for the Stirrups and they were of 8mm diameter. The main longitudinal GFRP bars were of 10mm diameter of top reinforcement and 12mm diameter of bottom reinforcement. The beams were tested with simply supported over two rigid supports. Two point loads were applied to all the beams. GFRP bras have a weaker elasticity modulus, which generate more deflection for equal loads and span. After the first crack, the beams reinforced with low stiffness GFRP bars in general deflected more rapidly and non-linearly with moment up to the ultimate moment. The load deflection response of various GFRP reinforced beams have been predicted and seems to be closely predict to the corresponding experimentally observed response.

Mohamed said et al (2014), investigated an experimental study of the flexural behavior of concrete beams reinforced with locally produced glass fibre reinforced polymers (GFRP) bars. The test results revealed that the crack widths and mid-span deflection were significantly decreased by increasing the reinforcement ratio. The ultimate load increased by 47% and 97% as the reinforcement increased.

Fergani et al (2015), examined the behavior of GFRP bars it is embedded in concrete or immersed in alkaline solution and exposed to temperatures varying from 20 C to 60 C. After exposure specimen tested in direct tension to assess environmental effects on their residual tensile strength and elastic modulus. It is concluded that the largest deterioration in mechanical properties was found for the specimens exposed to 60C which corresponds to the strength retention of about 80%.The tensile strength of specimens conditioned at 20C and 40C were not affected significantly and an average reduction in strength is 5%.the analysis of some initial results from tests on GFRP bars exposed to different simulating environments as confirmed that temperature is critical parameter when estimating the residual mechanical properties of FRP bars.

Priyanka et al (2016), presents that the use of hybrid reinforcements results in increasing the flexural behaviour and corrosion resistance. Test results of 8 concrete beams reinforced with steel, GFRP rods and hybrid reinforcements, stirrups placed at different spacing's of 150mm and 300mm. Reinforcement used were high yield strength deformed bars of 10mm diameter stirrups made from TMT of 8mm diameter. Yield strength of steel reinforcement is determined by standard tensile test.
Hybrid reinforcement: Steel reinforcement of diameter 10mm is wrapped with bidirectional GFRP sheet at one layer. Diameter should be increased while wrapping. Yield strength is determined by tensile test, respectively from ACI440 IR-6. It is concluded that for all same value of applied load, all strengthened beams exhibited smaller mid span deflections.

Marvel Dharma et al (2016), concludes that GFRP bars being high strength, low self-weight and non-corrodible remains better replacement for steel bars. Its low elasticity modulus and brittle nature reduces elasticity of GFRP RC beams. Steel fibers and steel reinforcements are added to improve ductility. Designed according to ACI 440 IR-06. With reinforcement more than 2% of GFRP stress does not increase. At service load crack width of FRC beams were smaller than plain concrete beam, especially at service loads. By improving concrete properties, adding fibres proved to be an effective way to enhance the ductility of FRP reinforced system. Tensile strength of GFRP bars decreases with increase in diameter.

Manjubashiniet al (2016), studied involves in using GFRP bar as a replacement of steel bars along tension side of the beam. About two beams of conventional M25 grade concrete and a longitudinally replaced GFRP beams is casted and tested from its flexural behavior. The beams are subjected to two-point loading under a simply supported condition GFRP bars are used for its excellent corrosion resistant property**.** This study involves using GFRP bar as a replacement of steel bar along tension side of beam. Two beam of conventional M25 grade concrete and a longitudinally repeated GFRP beams is casted and tested. Concluded that deflection is found to be 20% less in GFRP reinforced beam than conventional beam.

Seshadrisekhar et.al (2016), studied the effect of epoxy bonding of GFRP laminates offers strengthening corroded beams in flexure. Concrete beams strengthened with UDCGFRP laminates exhibit higher load carrying capacity and ductility. Corrosion test: is done that specimens were placed in a tank with 3.5% NaCl solution used as an electrolyte. Adequate submersion is followed. Specimen is provided with direct current power supply with output 11Amps.Static test results that beam strengthened with externally bonded UDCGFRP laminates exhibit increased strength enhanced flexural stiffness and sufficient ductility.

Rahul Dubey et.al (2016), studied the effect of corrosion on uncovered beams using impressed current technique where beams will be exposed to a DC current of 15V for a period of 150 hours and decrease in strength of unexposed and exposed beam would be noted. It is concluded that salt present in solution of immersed current technique, does not affect much on compressive strength of concrete, but application of FRP sheets increases the compressive strength of concrete cubes, flexural strength and compressive strength.

3. CONCLUSION

From above literature study carried out, the following points about GFRP rebar are observed:

- GFRP rebar are known for their abrasion and corrosion resistant properties because of the combination of two or more different constituents like fibre and resin into a unique material.

- It is studied that FRP products are generally made using polyester or vinyl ester resins which posses great thermal, physical and corrosion resistance.
- Alkali attack could not be detaining the GFRP reinforcement material.
- GFRP reinforced structures are projected to last four times longer than steel reinforced structures.
- No evidence of deboning between GFRP and concrete is occurring.
- No detritions of GFRP reinforcement took place in any their field demonstration structures.
- Fatigue effects – fatigue load cycles resulted in approximately 50% loss in the bond strength of sand coated GFRP bars to concrete
- GFRP rebar slabs experienced 2.5 times longer than steel reinforced slabs.
- GFRP slabs last 20 times longer than steel reinforced slabs when exposed to heavy fatigue loads.
- It is found that deflection in GFRP reinforced beam is 20% less than conventional beam.
- Aqueous solutions with high values of PH are known to ecode the tensile strength and stiffness of GFRP bars.
- It is found that the type of glass fibers resin and manufacturing process could lower the tensile capacity in the range of 25-100%.
- GFRP rebar in concrete beam gives better resistance to load carrying capacity.
- GFRP bars low elasticity modulus and brittle nature reduces ductility of GFRP RC beams
- It is found that the type of glass fiber tensile strength reduction in GFRP bars ranging from 0% to 75% of initial values.
- Tensile stiffness reductions in GFRP range between 0% and 20% in many cases.
- The matrix not only transfers the load between fibres but also prevents GFRP rebar from fracturing on exposure to adverse environmental factors.
- If young's modulus lower than steel one thus cracks opening in the service conditions are high reducing the production role of concrete around rebar.
- It is found that reduction in the bond strength depends on the transverse coefficients of thermal expansion.
- Specimens with thicker concrete covers show better bond durability.
- As degradation progressed the pore distribution in GFRP rebar increases which reduces the mechanical performance.
- The use of GFRP in concrete has given greater flexural strength.
- Smaller bar diameters seem to be more susceptible to bond damage due to fatigue loading.
- GFRP in concrete reduces the cracks under loading conditions.
- The use of GFRP rebar in beam has given good shear capacities and bending moment.
- It is found that GFRP had better residual tensile strengths in water and alkaline solution.
- The GFRP rebar exhibited significant performance degradation to 50-60% of its initial bond strength following a 50-day exposure in 3% NaCl solution at 60℃.
- The SEM analysis clarified that how micro structural degradation of GFRP rebar was caused by increase in pores, which resulted in polymer matrix delaminating, cracks and a reduction in the cross sectional area of the glass fibers. This contributed to the reduction in the mechanical performance of GFRP rebar.

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