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Effect of Potable, Acidic and Alkaline Water Curing on Flexure Strength of Strengthened and Unstrengthen Reinforced Concrete Beams

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ABSTRACT
The rapid growing population has resulted into the need of additional capacities of existing infrastructure facilities, commercial buildings etc. Also, the revisions of codal provisions has made many existing structures fall out of the safety criteria mandated by these provisions. In such scenario, from environmental point of view it is always better to strengthen the existing structure than demolish it and cause pollution. Such structures are made to withstand greater load than their capacity by means of supplementary systems also known as strengthening schemes. Recently, Fiber Reinforced Polymer (FRP) is in wide use in strengthening aspect due to its various advantages. Also, Potable Water is a scarcest commodity these days. Its significance in construction industry have been vital. Concrete and water being the most utilized construction materials, this paper examines the effect of different pH water levels on flexure capacity of concrete beams with and without the strengthening system. Eighteen numbers of concrete beams with conventional reinforcement are casted with size of 500x100x100 mm^3. These beams are divided into six categories so that each category has three number of beams. The beams are categorized based on the FRP application and pH value of curing solution. Three types of water is used with pH in the range of 4 to 5, pH of 7.5 and pH in the range 9 to 10. Single layer of Glass Fiber Reinforced Polymer (GFRP) fabric sheet is used for flexure strength enhancement. All beams are tested using flexural test till failure. Salient points viz. load and deflection at which first crack, service and failure. These points are noted for each beam and average of three beams of a group is presented as final reading. Suitable conclusions are drawn from these test results.

Keywords: fiber reinforced polymer, acidic water curing, alkaline water curing, flexural strength.

INTRODUCTION

Water is one of the most crucial commodity of planet earth. Though majority of portion of earth is occupied by oceans, the amount of potable water is very less when compared to total water availability. 97% of water on Earth is saline in nature whereas remaining 3% is in the form of fresh water. Out of total fresh water around (68.9%) is in the form of frozen glaciers and polar ice caps and remainder as unfrozen fresh water in the form of groundwater (29.9%) (Cassardo & Jones, 2011). Construction industry is among the basic requirements of society for shelter purpose. Majority of construction are either reinforced concrete structure or steel structure with RC structures occupying major share. Many country codes suggest use of potable water for mixing of concrete as well as for curing purpose, which put a strain on available quantum of fresh water as this activity requires huge amounts of water (Fadil et al., 2023; Wegian, 2010). Considering this, various researches have been carried out to study the effect of wastewater in mortar and concrete preparation as well as curing purpose (Akinkurolere et al., 2007; Susilorini, 2005). The various type of water used for study includes kitchen wastewater, washing center wastewater, industrial wastewater, Sea water, ground water, untreated river water etc (Emmanuel et al., 2012; Dimri et al., 2015; Larsen et al., 2016; Miller et al., 2018;). Many studies concentrated on cube strength of concrete specimens. It is observed from experimentation that the use of wastewater increases the initial strength of mortar as well as concrete but causes detrimental effects in long term (Dauda et al., 2018; Islam et al., 2012).

Many exiting structure needs strength enhancement due to various reasons viz. change in use, loss of strength due to accidents, old age of structure etc. In such cases, it is proposed to either demolish the structure and reconstruct it or increase its strength by various means viz. using pre-stressing, concrete encasing, steel plates attaching, FRP wrapping etc. Considering the pollution associated with demolition of structure, labor associated with it and wastage of valuable construction material resources makes it undesirable. Thus, in most of the cases, the strength of individual members is increased using strengthening techniques. The structural members for a building consists of beams, columns, slabs, foundations, beam-column joints, walls etc. Strengthening schemes associated with each such member is based on the performance, functional and strength requirement of that individual member. Columns need to carry axial loads primarily hence their axial strength is of critical importance, similarly beams carry flexural loads hence their flexural or strength in bending is of critical importance along with shear capacity. The current study focuses only on beams as structural members for strengthening with flexural strength evaluation as the main concern.

FRP has gained popularity in civil engineering as a material of different advantages and minimum drawbacks. Its lightweight has proved it very convenient in its applications in Buildings construction. Various studies states FRP as the most preferred and advantageous material of strengthening and retrofit. FRP is also experimentally established to enhance shear as well as flexure strength of Reinforced Concrete (RC) girders of bridges (Kachlakev & McCurry, 2000; Li et al., 2008). Increase in number of layers of FRP is said to increase the strength, though not exactly in multiple of initial strength enhancement (Pham & Al-Mahaidi, 2004; Hadi, 2003). Difference in strength gain due to difference of FRP width is also recognized and proven (Jumaat & Alam, 2006). The effectiveness and interaction of FRP along with different types of concrete has also been studied in previous researches (Lu, 2010).

From the literature studied, it is found that various studies have been carried out to investigate the effect of different types of water on compressive strength and splitting tensile strength of concrete. In practical, the concrete members acts as compression or flexure members. Also, the effectiveness of strengthening against demolition for upgradation of structures is validated. Thus, it becomes inevitable to study the effect of different types of water on such strengthening schemes.

The current study proposes the experimentation in the form of flexural test of standardized beams to assess the effect of different type of water curing on flexure strength of beam specimens along with the effect of such water types on flexure strength enhancement of beams when strengthened with GFRP. The FRP used for the research is GFRP. The fibers are of E-glass type. Epoxy is the polymer matrix and adhesive for the FRP scheme. All the beams have same size and reinforcement to compare the results. Standard Beam size of 500x100x100 mm^3 as defined by IS code is selected. Three beams are cured using normal potable tap water at laboratory conditions (GR-1), three beams are kept in acidic water with pH value in the range of 4 to 5 (GR-2), and similarly, three beams are kept in alkaline water pH solution of value in the range of 9 to 10 (GR-3). Remaining nine beams are applied with GFRP fabric sheet in single layer only. Out of these nine beams, three beams are cured using normal potable tap water at laboratory conditions (GR-4), three beams are in acidic water with pH value in the range of 4 to 5 (GR-5), and similarly, three beams are kept in alkaline water pH solution of value in the range of 9 to 10 (GR-6).

MATERIALS

Concrete

For preparation of M30 grade of concrete, ordinary Portland cement of 53 grade is used. The OPC-53 grade conform to IS 12269:1987. The brand name of the cement is Birla Super Cement. Standard tests on cements are performed to ensure its quality as per IS guidelines. The properties of cement are given in Table 1.

Fine aggregates (FA) in the form of crushed sand is used for the study. These aggregates are passed through 4.75 mm sieve for usage. Coarse aggregate (CA) of 20 mm size are used for the experimentation. The flaky and elongated particles are separated from the lot of CA before using it for actual casting. The properties of fine aggregates and coarse aggregates are given in Table 2. Normal tap water available at laboratory is used for concrete preparation.

In this experimental study the mix proportioning method is adopted from, Indian Standard for concrete mix proportioning – guidelines IS: 10262-2009, to arrive at a final mix proportion. The final mix proportion for the study is obtained by volume of ingredients in terms of weight. The final mix proportion used is given in Table 3.

Reinforcement

High strength deformed steel bars conforming to IS 1786 are used. The reinforcement was free from rust. Steel is used as longitudinal as well as transverse reinforcement. Longitudinal reinforcement consisted of two bars of steel with 8 mm diameter. The longitudinal bars are provided along full length of beam with cover of 20 mm. Transverse reinforcement is in the form of two legged stirrups of steel with 8 mm diameter. The spacing of stirrups is 50 mm in the shear zone of beams i.e. from end to one third of the beam span under testing as shown in Figure 1.

Table 1. Properties of cement

Properties	
Specific gravity	3.15
Standard consistency	38%
Initial setting time	175 minutes
Final setting time	542 minutes

Table 2. Properties of fine and coarse aggregates

Properties	
Specific gravity of FA	2.60
Specific gravity of CA	2.88
Grade zone of FA	Grade I
Maximum nominal size of CA	20 mm

Table 3. Final mix proportion

Description	Mix proportion (by weight)	Quantities of materials (in kg/m^3)
Cement	1	354.78
Fine aggregate	2.08	739.94
Coarse aggregate	3.34	1184.34
Water	w/c = 0.54	191.58

Fiber reinforced polymer

E-glass fibers (Alumina-borosilicate glass) and epoxy as polymer matrix made the GFRP used for current experimentation. The fibers are continuous with maximum orientation along one single direction i.e. uniaxial GFRP. The tensile strength of GFRP is in the range of 2000 to 2200 MPa. The GFRP is checked for any discontinuity of fibers, if found that portion of GFRP fabric sheet is discarded. Only continuous fiber GFRP is used for experimentation. The properties of glass fibers are given in Table 4.

Binding agent

A thermoset polymer namely, Epoxy is used as a binding agent between GFRP and concrete surface. The binding agent is in two parts, Primer and saturant. The primer is thinner form of epoxy as compared to saturant part. The properties of epoxy used are given in Table 5.

Water used for curing

Water used for curing was divided into three types based on its pH level as potable water, acidic water and alkaline water. The properties of aqueous solutions used for curing is given in Table 6.

Table 4. Properties of E-glass fibers

Properties	
Typical diameter (μm)	10
Specific gravity	2.50–2.55
Modulus of elasticity (GPa)	73
Tensile strength (MPa)	2200
Ultimate elongation (%)	3–5
Humidity absorption (%)	0–1

Table 5. Properties of epoxy

Properties	
Specific gravity	1.2
Modulus of elasticity (GPa)	2-6
Tensile strength (MPa)	35–130
Compressive strength (MPa)	100–200
Elongation (%)	1–8.5
Coeff. of thermal expansion ($10^{-6}/{}^{0}C$)	45–70
Water absorption (%)	0.1–0.4
Poisson's ratio	0.37

Table 6. Properties of curing water

Water type	pH	Temperature, °C	TDS, mg/l
Potable water	≈ 7.5	19	134
Acidic water	4 – 5	23	197
Alkaline water	9 – 10	22	528

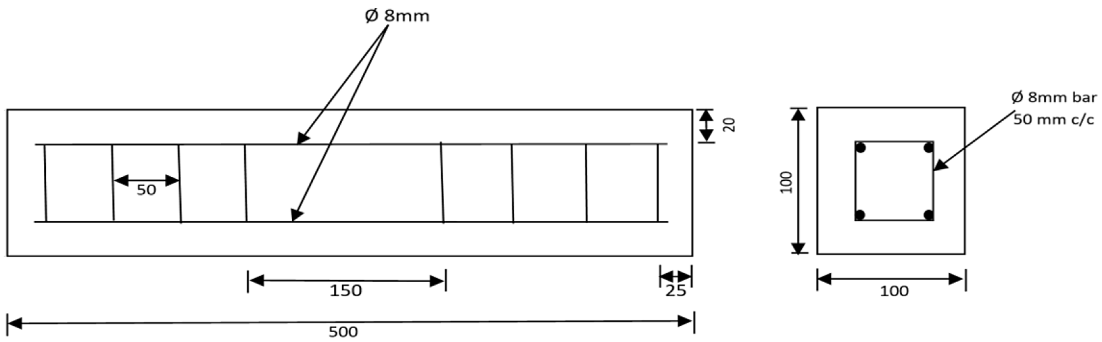

Fig. 1. Reinforcement detailing

METHODOLOGY

The RC beams were casted using steel molds in laboratory. Oil was applied to all the molds to avoid sticking of concrete to mold. As per the mix design, concrete constituents are mixed in proportion of their weights in laboratory rotary concrete mixer. Reinforcement skeletons are placed in the mold such that the required clear cover is obtained by using fillers. Fresh concrete is placed over reinforcement and molds are vibrated for avoiding air bubbles and proper compaction of concrete. The molds are opened after 24 hrs of placing of concrete. The beams are then water cured for a period of 28 days. After three days of air curing, the FRP strengthening scheme is applied to beams. The application of FRP is explained in next paragraph.

The main aim of the experimentation is to observe the effect of different types of water on flexure strength of RC beams. The RC beams are categorized into two parts further i.e. Unstrengthen and Strengthen by using GFRP. For Strengthen RC beams GFRP needed to be applied at the bottom of the concrete beam. Firstly, the soffit of the beam is rubbed with polish paper to remove any uneven portion. The primer coat of epoxy is applied to beam soffit by covering all area. The coat is to fill in all pores of concrete and promote better bonding between GFRP and concrete. The primer coat is air cured, until it's tacky. After primer application, if beam soffit is still irregular, it is evened with epoxy putty/ mortar. The GFRP is measured and cut as per the size of beam specimens. GFRP fabric is uniformly spread over the soffit of beam to avoid any gaps/folds or air pockets. A roller is run over the GFRP fabric to ensure its uniform application. Once the fabric is in place, a coat of saturant is applied over fabric. The saturant is the main component ensuring bond between concrete and GFRP sheet. After saturation application, beams are air dried for three days and then subjected to aqueous solutions of different pH value. Once the curing is done, specimens are tested using four point bending flexure test until failure with test setup as shown in Figure 2. For deflection measurement a dial gauge is used with a least count of 0.1 mm. The least count of loading arrangement of UTM machine is 0.01 KN.

The beams of GR-1 and GR-4 are kept at laboratory condition submerged in potable water; GR-2 and GR-5 are kept in water of pH 4 to 5 as shown in Figure 3 and 4. Similarly, GR-3 and GR-6 are kept in water of pH 9 to 10 as shown in Figure 5. The salient point observation while testing are noted down as mentioned in next chapter. Conclusions are furnished based on the load and deflection values obtained during testing of beams. For comparison, salient point load values observed for GR-1 specimens are treated as base.

RESULTS AND DISCUSSION

The beams are divided into six groups of three beams each. The group are categorized based on the GFRP strengthening and the condition they are kept in viz. chemical solution with different pH value. The groups are defined as shown in Table 7.

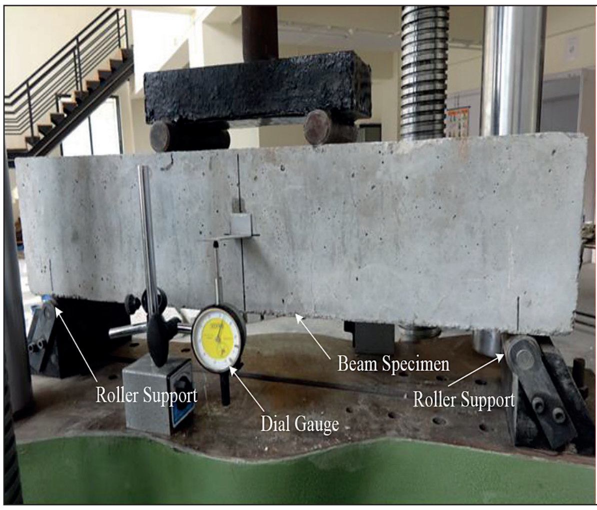

Fig. 2. Experimental test set up

Fig. 3. GR-2 and 5 beams curing

Fig. 4. GR-1 and 4 RC beams curing

Fig. 5. GR-3 and 6 RC beams curing

All the beams are observed carefully while testing under flexure loading arrangement. The deflection at which first crack is seen is noted along with its corresponding load value, which are designated as Y_1 and F_1 respectively. The load corresponding to serviceability criterion of central deflection (Clear span /325) was considered as service load, which are designated as Y_s and F_s respectively. The maximum value of load that beam sustains is noted along with corresponding deflection, which are designated as Y_{max} and F_{max} respectively. The summary of observations of load and deflection made at salient points during experimentation for individual group members are averaged and stated as group average values for corresponding group as shown in Table 8.

Table 7. Nomenclature of beam groups

Group	Description
GR-1	Unstrengthen ; Potable water curing
GR-2	Unstrengthen ; Acidic water curing
GR-3	Unstrengthen ; Alkaline water curing
GR-4	Strengthened GFRP ; Potable water curing
GR-5	Strengthened GFRP ; Acidic water curing
GR-6	Strengthened GFRP ; Alkaline water curing

Discussion on load at crack appearance

The load at appearance of crack is recorded for each of the three beams in group and averaged. The average value obtained are shown in bar chart format as shown in Figure 6. From the load values noted, it can be observed that the load value of beams without GFRP decreased for the appearance of crack when subjected to acidic and alkaline water curing. Similarly, the load value of GFRP strengthened beams at crack appearance

Table 8. Salient points load and deflection readings

Group	Y_1 (mm)	F_1 (KN)	Y_s (mm)	F_s (KN)	Y_{max} (mm)	F_{max} (KN)
GR-1	0.43	15.61	1.23	29.44	5.87	59.13
GR-2	0.39	14.94	1.23	27.31	6.19	56.12
GR-3	0.39	14.12	1.23	25.74	6.35	54.96
GR-4	0.36	17.37	1.23	33.93	5.13	78.15
GR-5	0.31	16.81	1.23	32.21	5.41	71.47
GR-6	0.32	16.43	1.23	31.74	5.63	68.22

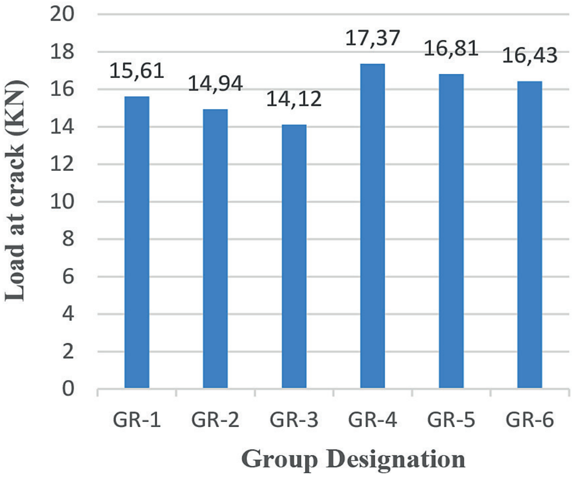

Fig. 6. Variation in load at crack

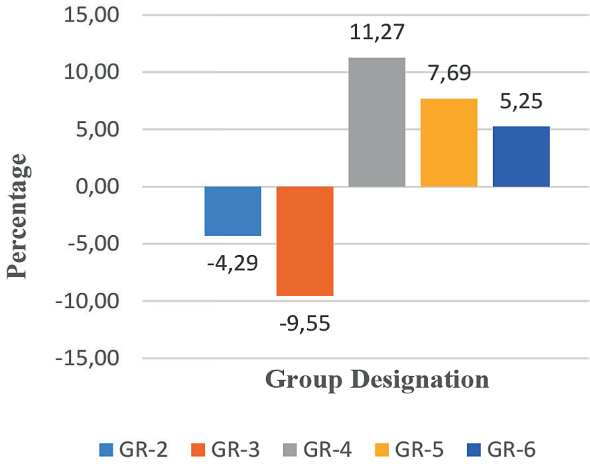

Fig. 7. Percentage variation in load at crack

also decreased when subjected to acidic and alkaline water curing. This decrease in load value of beams with and without GFRP is noted less for acidic water curing i.e. Aqueous solution with pH value of 4 to 5 as compared to that of alkaline water with pH value 9 to 10. The percentage decrease in load for beams without GFRP as compared to GR-1 beams is found to be -4.29% and -9.55% for curing with pH less than 5 and more than 9 respectively. The percentage increase in crack load for beams with GFRP as compared to GR-1 beams is found to be 11.27%, 7.69% and 5.25% for potable water curing, acidic water curing and alkaline water curing specimens respectively as shown in Figure 7. It is also observed that the load value of GFRP specimens are more than that of beams without GFRP. The percentage increase for same exposure beams with GFRP is 11.27%, 12.51% and 16.36% when compared to without GFRP beams.

Discussion on service load

The load at service is recorded for each of the three beams in group and averaged. The average value obtained are shown in bar chart format as shown in Figure 8. From the load values noted, it can be observed that the load value of unstrengthen beams decreased at service when subjected to acidic and alkaline water curing. Similarly, the load value of GFRP strengthened beams at service also decreased when subjected acidic and alkaline water curing. This decrease in load value of beams with and without GFRP is noted less for acidic water curing i.e. Aqueous solution with pH value of 4 to 5 as compared to that of alkaline water with pH value 9 to 10. The percentage decrease in service load for beams without GFRP as compared to GR-1 beams is found to be -7.24 % and -12.57 % for curing with pH less than 5 and more than 9 respectively. The percentage increase in crack load for beams with GFRP as compared to GR-1 beams is found to be 15.25%, 9.41% and 7.81% for potable water curing, acidic water curing and alkaline water curing specimens respectively as shown in Figure 9. It is also observed that the load value of GFRP specimens are more than that of beams without GFRP. The percentage increase for same exposure beams with GFRP is 15.25%, 17.94% and 23.31% when compared to without GFRP beams.

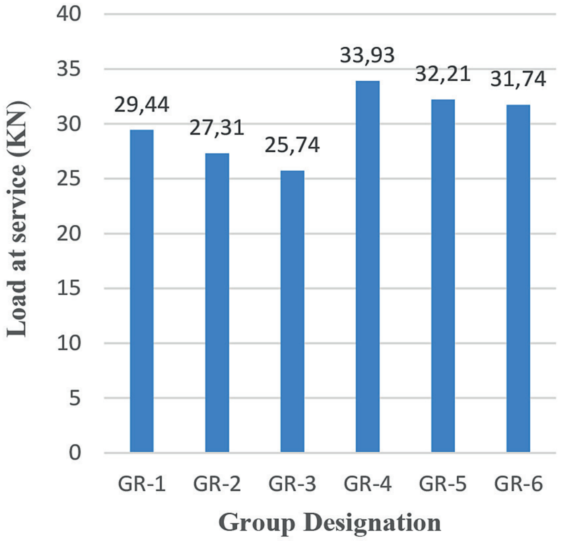

Fig. 8. Variation in load at service

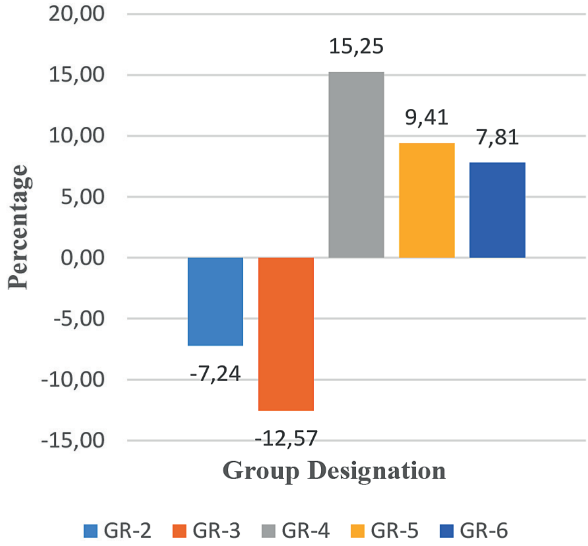

Fig. 9. Percentage variation in load at service

Discussion on maximum load at failure

The load at failure is recorded for each of the three beams in group and averaged. The average value obtained are shown in bar chart format as shown in Figure 10. From the load values noted, it can be observed that the load value of unstrengthen beams decreased at service when subjected to acidic and alkaline water curing. Similarly, the load value of GFRP strengthened beams at service also decreased when subjected acidic and alkaline water curing. This decrease in load value of beams with and without GFRP is noted less for acidic water curing i.e. Aqueous solution with pH value of 4 to 5 as compared to that of alkaline water with pH value 9 to 10. The percentage decrease in service load for beams without GFRP as compared to GR-1 beams is found to be -5.09% and -7.05% for curing with pH less than 5 and more than 9 respectively. The percentage increase in crack load for beams with GFRP as compared to GR-1 beams is found to be 32.17%, 20.87% and 15.37% for potable water curing, acidic water curing and alkaline water curing specimens respectively as shown in Figure 11. It is also observed that the load value of GFRP specimens are more than that of beams without GFRP. The percentage increase for same exposure beams with GFRP is 32.17%, 27.35% and 24.12% when compared to without GFRP beams.

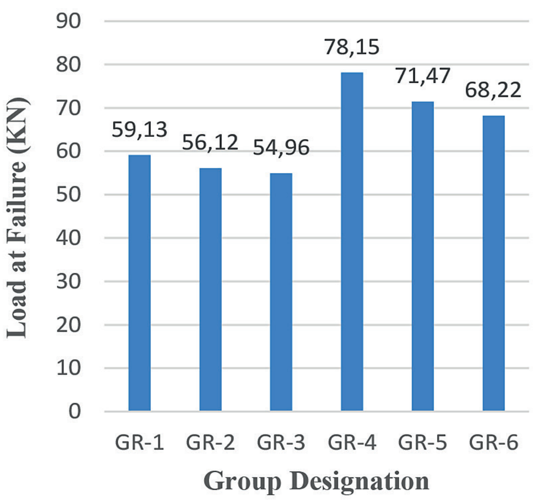

Fig. 10. Variation in load at failure

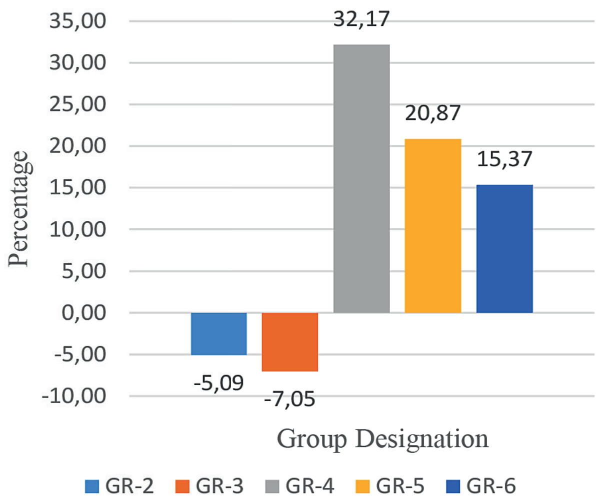

Fig. 11. Percentage variation in load at failure

Discussion on deflection at crack appearance

The deflection at appearance of crack is recorded for each of the three beams in group and averaged. The average value obtained are shown in bar chart format as shown in Figure 12. From the deflection values noted, it can be observed that the deflection value of beams without GFRP decreased for the appearance of crack when subjected to different types of water curing of different pH values. Similarly, the deflection value of GFRP strengthened beams at crack appearance also decreased when subjected to chemical solution curing. This decrease in deflection value of beams with GFRP is noted more for chemical solution with pH value of 4 to 5 as compared to that of pH value 9 to 10. Whereas for beams without GFRP decrease in deflection is same for both the solutions which is equal to 9.30%. The percentage decrease in deflection for beams with GFRP is found to be -16.27%, -27.90% and -25.58% for potable water, acidic water and alkaline water curing respectively when compared to deflection values of GR-1. The percentage decrease in deflection for same exposure beams at failure with GFRP is -16.27%, -20.51% and -17.94% for potable water, acidic water and alkaline water curing when compared to without GFRP beams.

Discussion on deflection at failure

The deflection at failure is recorded for each of the three beams in group and averaged. The average value obtained are shown in bar chart format as shown in Figure 13. From the deflection values noted, it can be observed that the deflection value of beams without GFRP decreased for the failure when subjected to chemical solution. Similarly, the deflection value of GFRP strengthened beams at failure also decreased when subjected to chemical solution. This decrease in deflection value of beams with GFRP is noted more for chemical solution with pH value of 4 to 5 as compared to that of pH value 9 to 10, similar observations were made for beams without GFRP wherein the decrease in deflection is more for pH less than seven solution. The percentage increase in deflection for beams without GFRP is found to be 5.45% and 8.18% for solution with pH less than 5 and more than 9. The percentage decrease in deflection for beams with GFRP is found to be -12.61%, -7.84% and -4.09% for potable water, acidic water and alkaline water curing respectively when compared to deflection values of GR-1. The percentage decrease in deflection for same exposure beams at failure with GFRP is -12.61%, -12.61% and -11.33% for potable water, acidic water and alkaline water curing when compared to without GFRP beams.

Failure mode

The failure pattern of all the beams is observed. It is seen that the beams in group-1,2 and 3 failed in flexure. The cracks started developing at the middle one third span of the beam in vertical direction. The first crack was observed near soffit which propagated towards the extreme fiber in compression. Almost vertically with very little inclination. The beams in group-4,5 and 6 failed in flexure along with major shear and some debonding of FRP from concrete surface near the

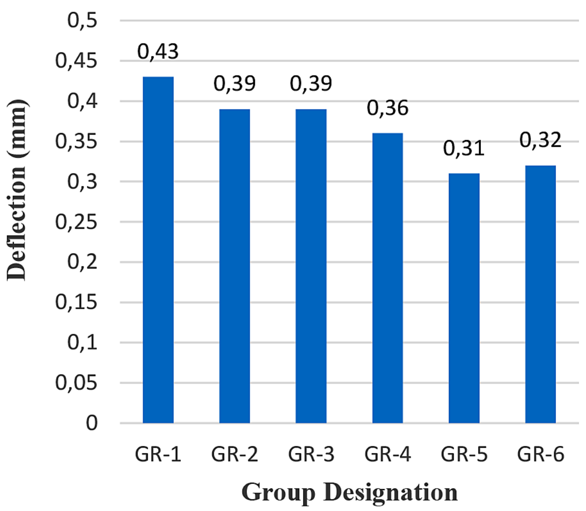

Fig. 12. Variation in deflection at crack

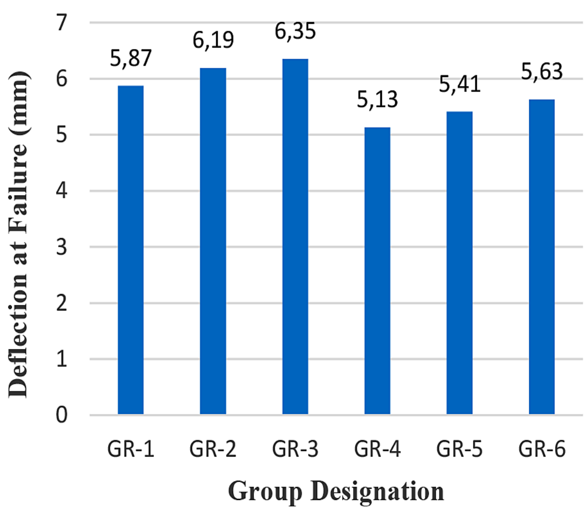

Fig. 13. Variation in deflection at failure

appearance of crack. The FRP in other portion remained intact throughout the testing. The concrete crushing was not observed at the points of contact between loading arrangement. The GFRP remained intact even in the portion outside of the beam span under testing. The cross section of failed beams remained more or less same at the end of beam span.

CONCLUSIONS

The current experimental study dealt with the flexural strength enhancement of reinforced concrete beams strengthened by GFRP sheets. Eighteen number of reinforced concrete beams were casted such that the strength in flexure is deficient when compared to shear strength of beam. The reinforcement detailing, mold size and material used for all the beams was same so as to have equal base for comparison. The flexure test result obtained led to following conclusions:

1. Acidic water and alkaline water curing caused decrease in flexure load carrying capacity as well as decrease in deflection at failure of strengthened and unstrengthen RC beams as compared to potable water curing.
2. The flexure load carrying capacity of beams at failure with same type of water curing showed more decrease in unstrengthen beams than strengthened beams.
3. Acidic water and alkaline water curing is found more detrimental to Unstrengthen beams than strengthened beams.
4. The effectiveness of strengthening scheme effect is found to be reduced due to acidic water and alkaline water curing.
5. Alkaline water showed more detrimental effects than Acidic water in strengthened beams validating susceptibility of GFRP to high pH level curing.

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