The Effect of Jacketing on Flexural Capacity of Concrete Beams Reinforced by Glass Polymer Bars

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Abstract - Ferro concrete is a kind of material which is widely used in civil engineering structures due to its proper compressive strength, low cost, and raw material availability. However, cement paste reinforced concrete, ordinary aggregates, and steel bars have disadvantages such as high weight, steel corrosion, and cracks caused by shrinkage which limit their uses in some cases. In order to compensate for these deficiencies, a special type of concrete has been innovated in which light aggregates and small separate pieces of fiber are used, and instead of steel bars, fiber polymer composite bars are used for resolving the problem of steel bar erosion in coastal areas. Since using these special concretes is becoming common due to their undeniable advantages and the use of them is justified and necessary in countries such as Iran, studies should be done on their different practical aspects. In this research, flexural behavior of reinforced concrete bars made of glass fiber reinforced by polymer rebar (GFRP) is studied by preparing a laboratory plan. Six laboratory samples with the ratios of ½ Pb, 1/7 Pb, and 2/3 Pb were built by jacketing and the studied parameter was flexural strength of the bars. The results of the experiments suggest that with the increase of P value in jacketing mode, flexural strength increases, and by jacketing using tie bars in glass fiber reinforced polymer concrete rebars, with the increase of P value, flexural capacity rate increases.

Keywords: glass fiber reinforced polymer rebar (GFRP), reinforced concrete bars, flexural capacity of concrete bars

1. Introduction

Concrete is the most widely used building material and in most countries, the ratio of consumption of concrete to steel has become more even more than 10 to 1. The only material which is used by human with the same rate is water. Concrete has advantages such as high resistance to water, being easily formed in different shapes, being cheap, and availability of the raw material. Also, compared with steel, it needs less maintenance and has a proper resistance to high temperature, and since it is exposed to less local tension fields, fatigue is not considered as an important problem for that. In spite of the mentioned advantages of concrete, due to the existence of different materials in concrete and interaction of these materials especially between the aggregates and cement paste, there are still many complexities and unknown matters about this material and the final product resulted from building it. In some cases, concrete structures will not meet the operation needs. Disadvantages of concrete structures include low tensile strength, erosion of steel, easy creation and expansion of crack, and their high weight.

Researchers have suggested using galvanized sheets for resolving this problem (steel + zinc alloy), but this alloy causes a chemical reaction in an acid environment and the bond between steel and zinc breaks. Various companies have proposed different suggestion for solving this problem, for example, using electrostatic spray, powdered composite adhesives, and coating steel with oil. Finally, US Federal Highway Administration suggested using epoxy steel (ACI Committee, 2001: 440).

Researchers of building industry have always tried to eliminate the deficiencies of concrete structures and they have proposed different methods for this purpose, some of which are mentioned in the following:

FRP bars are used for preventing erosion, increasing strength, and increasing damping; corrosion-resistance of steel in alkalic environment which is used in reinforced concrete structures exposed to sea water, is the reason for using FRP as its alternative. Erosion resistance and tensile strength of composite materials can be four times more than that of steel. Due to their damping coefficient which is caused by their inelasticity, these materials damp the absorbed energy.

Using fibers for increasing tensile strength and decreasing the width of cracks: fibers are used in different sizes and forms made of different materials including steel, paste, glass, and natural materials. Using different amounts of fibers in mortar can increase the final tensile strength to some extent, but in these concretes, tensile strain at the time of collapse is much more than ordinary types, which is because of preventing the opening of cracks and converting a large crack to several small cracks.

In the recent 25 years, using alternative materials for concrete has increased under harsh environmental conditions. According to the released statistics, using FRP is more efficient, compared with the repairs required due to erosion. Designing lighter and stronger structures, simplicity of installing FRP systems, very high tensile strength in pre-stressed systems, and less fatigue of FRP materials, in comparison with steel are other major reasons for using these materials.

However, in reinforced concrete made of FRP bars, due to impossibility of flow of FRP bars, they have a much lower plasticity than steel reinforced bars. Therefore, FRP reinforced bars are crispy and fragile and in designing these bars, plasticity can be achieved more difficultly than steel reinforced bars. FRP composite bars have become an alternative for steel bars in reinforced concrete. Due to no erosion, using these bars will completely solve the problem of carbonation and chlorination which are the most important destructive agents in reinforced concrete structures (Mostowfi Nezhad, 2012).

Usually, for preventing the tear of polymer bars, they are designed in such a manner that concrete break first occurs in compression area. Since concrete can be considered as semi-crispy materials, after the beam's reaching its capacity, burst of the compression area of the concrete leads to decreased section compression force and so, decreased flexural moment. It is the decreased plasticity of beam after reaching flexural capacity. FRP armatures are classified into different types in terms of the type of the fiber and matrix used in their structure, production manner, and resin material. In the following, some of the common fibers will be briefly described (Mostowfi Nezhad, 2012). One of these fibers is carbon fiber reinforced polymer (CFRP). These fibers are made of bitumen which is obtained from coal distillation,and has low elasticity modulus and artificial silk. Formation of this type of fiber requires a temperature of at least 1000 ˚C. The other type of fiber is aramid fiber reinforced polymer (AFRP) which has a low compression strength due to buckling. So, for improving that, it is combined with carbon fiber or glass fiber. Ultraviolet has a destructive effect on these fibers. It should be mentioned that aramid fibers can be hardly cut by ordinary tools, and special cutting devices are needed (Barkhordari and Amani, 2008). The study performed by Chitsazan et al (2010) was focused on flexural behavior of concrete beams reinforced by GRFP. In this research, two types of concrete have been used. The first one has a nominal strength of 40 mega Pascal and the other one is concrete with a high strength of 70 mega Pascal. Type 2 Portland cement is used and the diameter of the largest aggregate is 9/5 mm.

Several studies have been conducted on reinforced concrete beams.Karayannis, et al. (2018) examined the reinforced concrete beams with carbon fiber reinforced polymer bars under increasing static loading, and it was found that the application of local confinement conditions along the anchorage lengths of the carbon-FRP bars in some specimens seemed to influence their cracking behavior. Tarigan et al (2018) compared the flexural strength of reinforced concrete beam using steel plates and Fiber Reinforced Polymer (FRP), and they concluded that the beam with CFRP is the best choice for external reinforcement in building technology than the others. Kadhim et al (2019) investigated the flexural strengthening and rehabilitation of reinforced concrete beam through using BFRP composites.El Zareef & El Madawya (2018) compared the ductile behaviour of beams reinforced with glass-fiber to beams reinforced with steel reinforcement. The deformability factor showed that, the ductile behaviour of GFR beams enhanced by increasing the GFR ratio. Goldston, et al. (2017) experimentally investigated the flexural behaviour of high strength concrete (HSC) and ultra-high strength concrete (UHSC) beams reinforced with glass fiber reinforced polymer (GFRP) bars.

In a study performed by Tavares D. H. (2008), flexural toppling of the samples was caused by concrete compressive crush after steel yield or tear of GFRP bars.

According to the mentioned facts, the main goal of this research is investigating the effect of jacketing on flexural capacity of concrete beams reinforced by glass polymer bars.

2. Designing criteria and test hypotheses

The fundamental assumptions for calculating the flexural capacity of FRP bar reinforced concrete section are as the following:

Strain in concrete and FRP is proportional to the distance from the neutral axis.

The section remains flat before and after loading (linear changes of strain in section height)

The highest compressive strain of the concrete is considered as 0.003.

Tensile strength of the concrete is disregarded.

Tensile behavior of FRP armatures is linear until the collapse moment.

There is full adhesion and absorption between concrete and FRP.

The relationship between the nominal flexural capacity of M n section and final flexural capacity which is calculated by using factored loads is as the relation (1):

$$Mn\ Ø \geq M\ u \qquad (1)$$

Ø is the coefficient of strength decrease. Nominal flexural strength of a concrete section reinforced by FRP armature can be calculated based on the equilibrium relation of internal forces and, consistency of strains, and the type of section break.

Flexural capacity of concrete section reinforced by FRP depends on whether the section is destructed by concrete collapse or by armature collapse. The type of break can be determined by comparing the percentage of FRP section armatures with the percentage of balanced reinforcement, a situation in which the armature and the concrete simultaneously reach the final strain. Since FRP armatures do not flow, balanced percentage of FRP armatures is calculated by using the tensile strength of the design of these armatures. The ratio of FRP armatures of P_f section is obtained from relation (2) and the ratio of armatures in balanced mode P_{fb} can be obtained from relation (3):

$$\rho_f = \frac{A_f}{b.d} \tag{2}$$

$$\rho_{fb} = \text{۰/۸۵}\ \beta_{\text{۱}} \frac{f'_c}{f_{fu}} \frac{E_f\,\varepsilon_{cu}}{E_f\,\varepsilon_{cu} + f_{fu}} \tag{3}$$

If the reinforcement ratio is less than the balanced ration ($P_f < P_{fb}$), failure of armature occurs, otherwise ($P_f > P_{fb}$), concrete break occurs.

When ($P_f > P_{fb}$), concrete is the determinant of the section capacity. Based on the relations of static forces and consistency of strains, relations (4) can be proposed for calculating the section flexural capacity in this situation.

$$M_n = \rho_f\, f_f (1 - 0.59 \frac{\rho_f\, f_f}{f'_c}) bd^2 \tag{4}$$

$$f_f = (\sqrt{\frac{(E_f\,\varepsilon_{cu})^2}{4} + \frac{0.85\beta_1 f'_c}{\rho_f} E_f\,\varepsilon_{cu}} - 0.5 E_f\,\varepsilon_{cu}) \le f_{fu} \tag{5}$$

2-1. The used materials

In this research, compressive strength test was done for all the cubic 15*15*15 samples based on BS 1881 part 116. The samples were taken out of the pond and their surface was dried. The tested cubic samples were placed between the two plates of loading device in such a manner that the sample surface was in contact with the cubic mold. Then, a vertical force was applied on the cubic sample by a device with constant speed, so that the cubic was broken as a result of the compressive force and it did not have the ability of transferring the force. The amount of the compressive tension was read on the digital screen and it was recorded. The number of samples used for 7 and 28-day compressive strength test was 6. The initial mix design is presented in table (1) and the results of 28-day compressive strength of the concrete have been presented in table (2).

Table1. The weight of the components of one-cubic-meter concrete

Water (kg/ m^3)	**Fine aggregate** (kg /m^3)	Coarse aggregate (kg/ m^3)	cement (kg/ m^3)
150	1050	800	350

Table2. The results of 8-day compressive strength of concrete

Sample no.	Cement content	Length	Width	Height	Slump	Special weight	Compressive strength
	kg/m3	cm	cm	cm	cm	gr/cm3	kg/cm2
1	350	15	15	15	5	2350	280
2	350	15	15	15	6	2350	278
3	350	15	15	15	5	2350	285

In this research, GFRP armature with the length of 230 cm was used. The properties of the used armature which are reported by the producer have been presented in table 3.

Table3. Properties of GFRP armature provided by the producer

Property	Tensile strength (MPa)	Elasticity modulus	Apparent color
GFRP armature	More than 1000	60	Gray

2-2. Geometric properties and putting bar in the samples

Properties of all the beams used in this research are presented in table (4).

Table4. Properties of the tested GFRP reinforced concrete beams

Beam name	The specific strength of concrete (mega Pascal)	Shear reinforcement	Compressive armature	Ration of tensile reinforcement	Ratio of balanced reinforcement	Type of tensile FGRP armature	Effective height of section	Total Section height	Section width	Beam length
				ρ	ρ b		D (mm)	H (mm)	B (mm)	L (mm)
B2S200	30	Φ	2 Φ 3	0/ 008	0/ 0069	2Φ06	250	300	200	230
B3S200	30	Φ	2 Φ 3	0/ 012	0/ 0069	8 Φ 06	250	300	200	230
B4S200	30	Φ	2 Φ 3	0/ 016	0/ 0069	0 Φ 06	250	300	200	230
BC2S50	30	Φ	2 Φ 3	0/008	0/ 0069	2 Φ 06	250	300	200	230
BC3S50	30	Φ 01@51	2 Φ 3	0/ 012	0/ 0069	8 Φ 06	250	300	200	2300
BC4S50	30	Φ	2 Φ 3	0/ 016	0/0069	0 Φ 06	250	300	200	230

3. Results

3-1. Study of crack and break of beams

Bs2200 beam which has two GFRP armatures with the ratio of 1/2 Pb in flexural area without jacketing and with the stirrup distance of at least 20 cm in the middle, its first flexural crack has occurred in the fixed anchor area with the load of 2/5 ton (figure 1, crack 1). With the increased load, other flexural cracks were also created in the middle of the two concentrated loads and after that, the first flexural-shear crack was created under the load of about 10 ton (figure 1, crack 2). Finally, under the force of about 20 ton, compressive concrete began to become destructed.

Figure1. GFRP reinforced concrete beam

BC2S50 beam which has two tensile GFRP armatures with the ratio of 1/2 Pb in flexural area without jacketing and with the stirrup distance of at least 20 cm in the middle, its first flexural crack has occurred under the load of 2/7 ton in the fixed anchor area (figure2, crack 1).With the increased load, other flexural cracks were also created in the middle of the two concentrated loads and after that, the first flexural-shear crack was created under the load of about 9 ton (figure 2, crack 2). Finally, under the force of about 25 ton, compressive concrete began to become destructed.

Figure2. GFRP reinforced beam

The results of testing the samples suggestthe effect of jacketing the tie bars on the behavior of the studied beams including their strength and flexural capacity.

3-2. The effect of jacketing on flexural capacity of the samples

The results of the tests on GFRP reinforced concrete beams and the chart in figure (3) show that the increase of flexural capacity has a direct relationship with increased p and jacketing of GFRP reinforced concrete beams. In GFRP reinforced concrete beams, with the increase of p by 40%, flexural capacity has been also increased by 20% in all the jacketed beams and in GFRP reinforced concrete beams with 1/2 Pb, the ratio of flexural capacity in jacketed beams has increased by 19% and for tensile GFRP reinforced concrete beams with 1/7 Pb and 2/3 Pb, the capacity of all the jacketed beams increases by 25%. In all the jacketed samples, increased P has led to increased flexural capacity of the sample, while this rate was higher in jacketed samples.

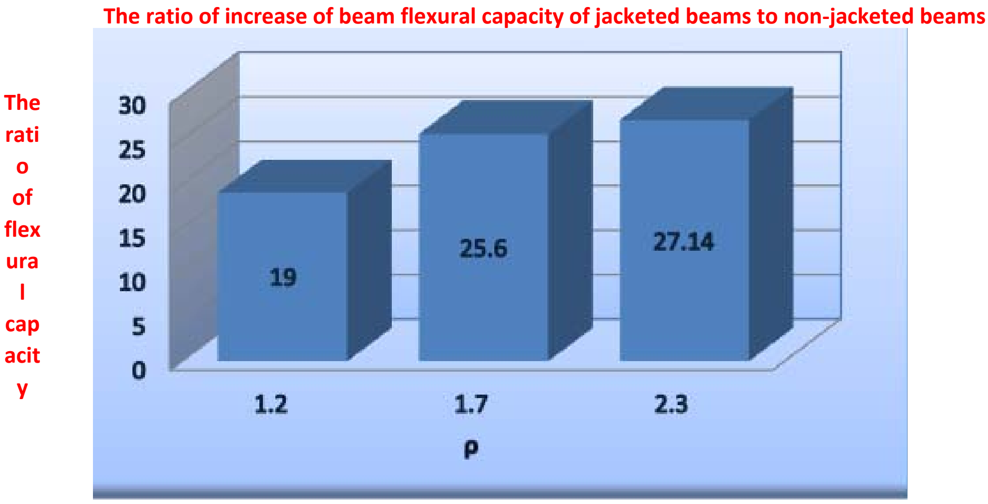

Figure3. The ratio of increase of beam felxural capacity

4. Conclusion and suggestions

1. In GFRP reinforced concrete beams which are jacketed, in spite of increase of P by 40%, flexural capacity has also increased by about 20%.
2. By using jacketing steels in GFRP reinforced concrete beams with 1/7 Pb and 2/3 Pb, flexural capacity also increases by about 25%, while for GFRP reinforced concrete beams with 1/2 Pb, flexural capacity of the jacketed sample has increased by about 14%.
3. By using jacketing steels in GFRP reinforced concrete beams with 1/2 Pb, their strength also increases by about 30%, while for GFRP reinforced concrete beams with 1/7 Pb, strength also increases by about 57%, and for GFRP reinforced concrete beams with 2/3 Pb, the strength increases by about 22%.

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