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Research Article

Fracture patterns and mechanical properties of GFRP bars as internal reinforcement in concrete structures

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ABSTRACT

Glass Fiber Reinforced Plastic (GFRP) composites as rolled bars can be used as steel rebar to prevent oxidation or rust which is one of the main reasons concrete structures deteriorate when exposed to chlorides and other harmful chemicals. GFRP is successful alternative for reinforcement with high tensile strength- low strain, corrosion resistance and congenital electromagnetic neutrality in terms of longer service life. The main goal of the study is to investigate the mechanical and bonding properties of GFRP bars and equivalent steel reinforcing bars then compare them. GFRP and steel rebar are embedded in concrete block with three different levels. Mechanical properties of GFRP and steel bars in terms of strength and strains are determined. On the other hand; modulus of elasticity of GFRP and steel bars, modulus of toughness and modulus of resilience were calculated using stress-strain curves, as a result of the experiments. Pull-out tests are conducted on each GFRP and rebar samples which are embedded in concrete for each embedment level and ultimate adherence strengths are determined in terms of bar diameter–development length ratio. Yield strength, strain and modulus of elasticities of GFRP samples are compared to steel rebar. According to the test results reported in this study, GFRP bars are used safely instead of steel bars in terms of mechanical properties.

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1. Introduction

The behavior of glass fiber reinforced plastic (GFRP) bars as internal reinforcement for concrete structures has been investigated in a number of studies that GFRP reinforcement bars can increase the ductility, toughness and strength of structural members. Although GFRP bars are now commercially available, many civil engineers are not familiar with using GFRP rods as internal reinforcement for concrete structures which are especially in highly aggressive environment conditions. High tensile strength is one of the most important features of GFRP that the others are corrosion resistance, environmental stability, light weight and excellent bond strength (Gangarao et al., 2007). Fiber reinforced plastic (FRP) is made of a polymer matrix laminated with fibers which are widely glass or carbon and embedded in a resin matrix (Anurag et al., 2015; Agarwal et al., 2010). The most used FRP reinforcement types today; glass fiber reinforced plastic (GFRP), carbon fiber reinforced plastic (CFRP), aramid fiber reinforced plastic (AFRP), and basalt fiber reinforced plastic (BFRP) are the main known FRP reinforcements. The surface properties of these reinforcements can be changed by using different methods during the production phase. The most commonly used resin types in FRP reinforcement production as binders are thermoset polymer resins epoxies, polyester and vinyl esters. FRP rods are produced by pultrusion method. In this method, glass fibers are passed through the thermoset resin tank and smeared into the resin. Resin-impregnated glass fiber fibers enter the preform and allow the air and excess resin to be filtered in them. In addition, the penetration of the resin into the glass reinforcement material is achieved. Its surface is covered with mixed fiber fibers to protect it from the atmosphere and other external factors. Then the material that enters the main

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mold turns into a rod shape. The resin-fiber ratio plays a decisive role in the behavior of FRP within the structure. The most commonly used materials for structural applications are steel, aluminum and wood. However, in some applications these materials are gradually being replaced by glass fiber for reasons such as low specific weight and durability. FRP reinforcing bars are useful for R.C. structures where the existence of steel would not be applicable due to limited steel resources and good corrosion resistance of FRP composites (Bhashya et al., 2015; Vicki and Charles, 1993). Durability of FRP reinforcing concretes have been investigated mostly in recent years (Chen et al., 2007; Wang et al., 2007). On the other hand, bond behaviour between FRP and concrete is a one of the key factor to mitigate adhesion problems. Mechanical adherence or bond behaviour of the FRP bars to the concrete is proper as well as steel bars (Lawrence et al., 1998; Tepfers, 2006; Achillides and Pilakoutas, 2004). Creep resistance of glass FRP bars is quite good (Najafabadi et al., 2018). FRP can be used particularly in marine structures or in the evaluation of marine content such as coral aggregates in concrete production (Yang et al., 2018). Temperature increase significantly affects FRP thermal deformations (Zaidi et al., 2017). The deformation in FRP embedded concrete under high temperature was affected by fiber type (Aydın, 2018). After seawater immersion on the GFRP bars at a high temperature, micro cracks and voids appeared between the surface resin and fiber of the GFRP bars, and serious debonding and deterioration of glass fibers occurred (Wang et al., 2018). Bond properties between FRP bar and concrete is affected by various parameters like diameter of bar, sand coating etc. (Rolland et al., 2018; Albayrak and Canbaz, 2015). The use of GFRP in civil engineering applications is becoming increasingly common. In Fig. 1, it is seen that GFRP is used in many civil engineering applications, primarily in transportation and coastal structures (Durmaz, 2018).

Fig. 1. Application areas where GFRP is used.

Due to the brittle structure of GFRP, there has not been enough studies on its behavior in the structure. For this purpose, in this study, bonding behavior of steel and GFRP bars were investigated by pull-out tests, and mechanical properties of GFRP bars were investigated. Also crack patterns of GFRP under bending and tensile were examined.

2. Experimental Study

2.1. Materials

Cement: CEM I 42.5 cement was used by production of Çimsa Eskişehir cement mill. The properties of cement are given in Table 1.

GFRP: In the experimental work, 12 mm diameter glass FRP rebars supplied from Dost Ltd.Co. These rebars were obtained by laminating glass fiber with epoxy recipe in one direction. The properties are shown in Table 2.

Steel rebars: In this study, 12 mm diameter S420 type steel rebars provided from İzmir Demir Çelik Sanayi Inc.Co. was used. The properties are shown in Table 3.

Water: Eskişehir tap water was used. The chemical analysis of the drinkable water is given in Table 4.

Aggregate: In this study, the crushed sand produced by Selka Concrete Company and natural river sands that are derived from Sakarya River were used. Table 5 gives the properties of the aggregate. The granulometry of aggregate is shown in Fig. 2.

Table 1. Properties of cement.

Final setting time, min.	Density, g/cm^3	Blaine, cm^2/g	Strentgh, MPa	Expension, mm
260	3.17	3750	49.5	1.3

Table 2. Properties of GFRP.

Modulus of elasticity, GPa	Strain, %	Diameter, mm	Tensile str., MPa	Weight, g/m
40	2.8	12	1000	200

Table 3. Properties of steel reinforcing bars.

Tensile / Yield	Yield str., MPa	Strain, %	Modulus of elasticity, GPa	Poisson ratio
1.15	420	10	200	0.30

Table 4. Chemical analysis of the water.

pH	NTU	Cl mg/l	Ca^{++} mg/l	SO_4 mg/l	Organic Material	CO^{-3} mg/l	FS0 mg/l	Mg^{++} mg/l	Total Salinity
7.7	<5	245.8	187	135	49	23	92	107,4	1540

Table 5. Properties of the aggregate.

Coarse aggregate		Fine aggregate		Water absorption, %
loose unit weight, kg/dm³	compact unit weight, kg/dm³	loose unit weight, kg/m³	compact unit weight, kg/m³	
1.7	1.9	1,5	1,7	0.6

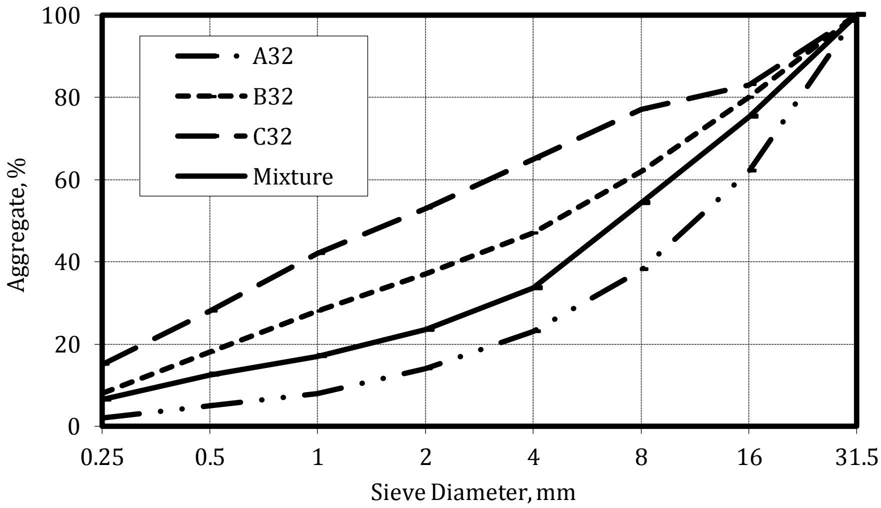

Fig. 2. Granulometry of aggregate mixture.

2.2. Method and tests

The purpose of this study is to investigate the bonding properties of FRP bars and compare them to that of steel reinforcing bars. In this preliminary experimental study, 12 mm diameter Glass FRP (GFRP) bars and 12 mm diameter S420 ribbed steel reinforcing bars were used. In the production of concrete basement, CEM I 42.5 type normal Portland cement and Eskişehir tap water were used. Three types of aggregates (0–4, 4–8, and 8–32 mm) were used for adequate gradation of concrete mixtures. The solid concrete basement on the dimension 35x50x100 cm³ by 0.5 water/cement ratio was produced. Composition of basement concrete was given in Table 6.

GFRP and steel bars were embedded perpendicular to the fresh concrete surface with quadrilateral meshing system. Concrete production, and rebar placement were shown in Fig. 3.

Fig. 3. Concrete production and rebar placement.

Table 6. Composition of concrete mixtures, kg/m³.

Cement	Water	0-4 mm, Crushed sand	4-8 mm, Crushed stone	8-32 mm, Crushed stone
300	150	900	700	400

The bars were embedded in concrete block with 3 different levels. Adherence (development) depth-diameter ratio (L/D) were considered 10, 15 and 20. Adherence strength of the bar specimens (Steel and GFRP) were determined by pull-out tests after 28 days shown in Fig. 4.

Fig. 4. Pull-out test.

Since concrete can be sufficient against the compressive strength, the tensile strength of FRP becomes important in strengthening. For this purpose, tensile and bending tests were conducted on reinforcing bars for determining the mechanical properties of FRP shown in Fig. 5.

3. Discussion

Bending tests with 90° and 135° angles were performed on 60 cm length GFRP samples and shown in Fig. 6. According to the bending test results; GFRP bars were ruptured after epoxy matrix phase and glass fibers were broken properly at inflection points. GFRP composites are not proper for bending because cannot make plastic deformations as a result of bending.

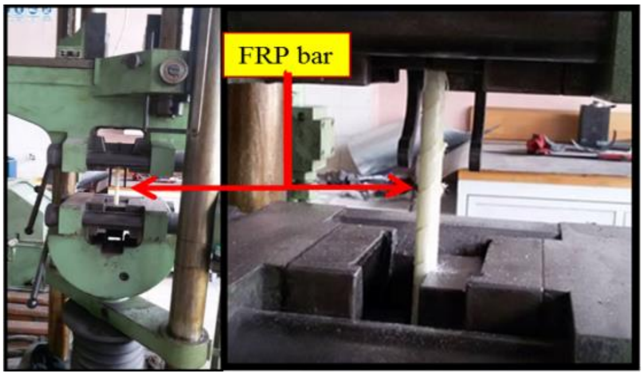

Fig. 5. Tensile tests conducted on reinforcing bars.

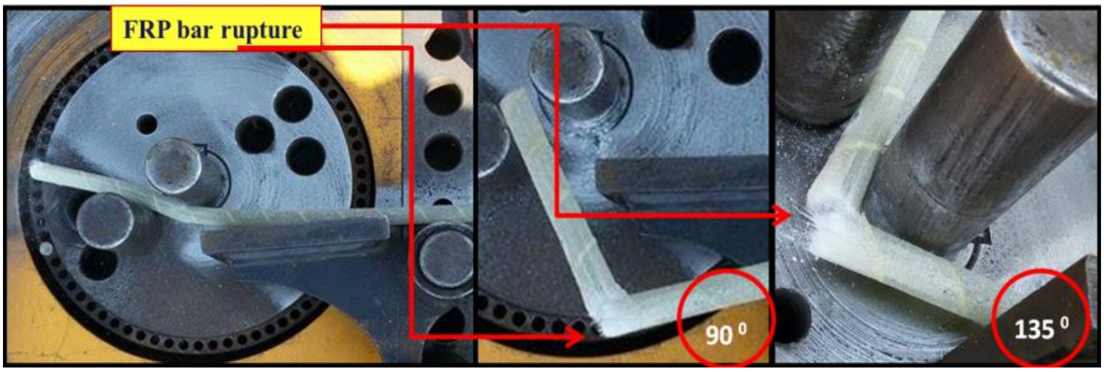

Fig. 6. Bending tests conducted on reinforcing bars.

As a result of the tension tests conducted on specimens, mechanical properties of the GFRP and Steel bars can be shown in Table 7. Tensile strength of GFRP bars are 93% of S420 steel bars approximately. On the other hand; modulus of elasticity of GFRP bars are less than 3.5 times to steel bars. Total elongation of GFRP bars are less than 5.5 times to steel bars while toughness of GFRP reinforcement was found to be about 15% of steel reinforcement.

Typical stress–strain curve for S420 and GFRP bars used in the study are shown in Fig. 7. In stress–strain curve for GFRP samples, the curve is linear until 150 MPa stress level and fibers were not ruptured suddenly after the maximum stress point. The percentage elongation of all the samples tested was less than the minimum requirement of 10% for GFRP.

Rupture patterns of GFRP and steel bars after tensile tests are seen in Fig. 8. Expected progressive necking during tension test was not being observed in low carbon steel bars whereas 45° brittle failures were observing. GFRP bars with epoxy were ruptured into large pieces under ultimate stress longitudinally then fibers were appeared and the stress was reduced without completely rupturing.

Table 7. Mechanical properties of the GFRP and steel bars.

	Yield Strength, MPa	Tensile Strength, MPa	Rupture Strength, MPa	Mod. of Elast., GPa	Elongation, mm	Reduction of Area %	Toughness Nmm/mm^3
S420	512.82	618.92	565.87	123.52	20	30.56	116
GFRP		574.71		35.92	3.7		17

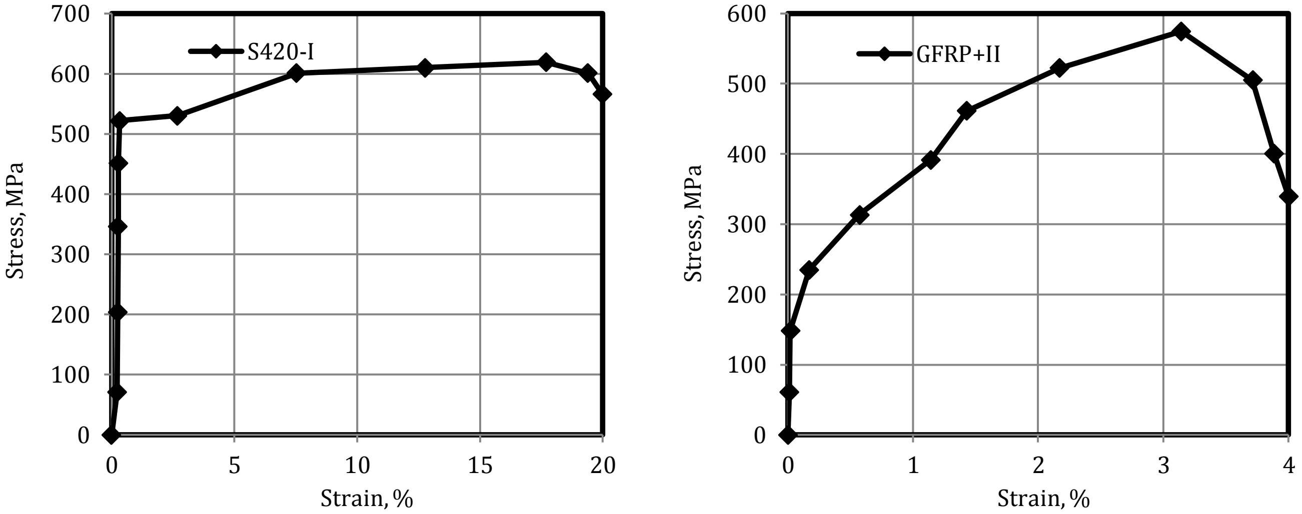

Fig. 7. Typical stress–strain curves for S420 and GFRP bars.

Fig. 8. Rupture patterns for S420 and GFRP bars.

Fiber type, resin type, surface properties, diameter, modulus of elasticity, embedment length, position of the reinforcement within the concrete, vertical and horizontal concrete cover, concrete strength, ratio of transverse reinforcement and the environmental conditions are the factors effecting the adherence of FRP (Basaran and Kalkan, 2020).

It can be expected that the adherence strengths of FRP reinforcements with concrete due to reasons such as the material properties of the FRP reinforcement are different and the production methods are different from the steel reinforcement-concrete adherence strength. Bonding behavior of steel and GFRP bars were investigated by pull-out tests. Adherence strength values were determined based on bonding forces and the relationships between development depth and bar diameter were given in Fig. 9. Adherence strength increased as the development depth increased. Adherence strengths of steel and GFRP bars were increased up to 90% while the development length increased. Adherence strengths of GFRP bars are 85% of steel bars initially and decreased into 80% whereas the development length increased. GFRP bars have good adherence strength even though it is not ribbed.

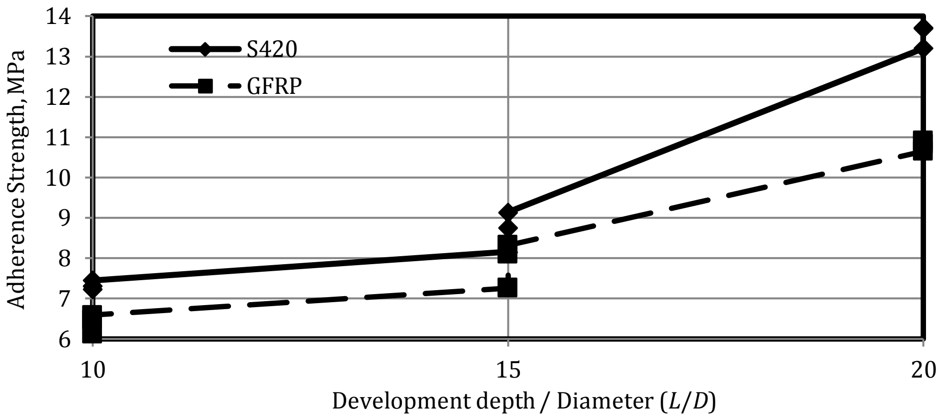

Fig. 9. Pull-out test results.

4. Conclusions

Preliminary test results that have been conducted on GFRP and steel bars indicate that:

- Deformation properties of GFRP reinforcements must be improved while tensile strengths of GFRP were enough in terms of mechanical behaviour. Using GFRP bars instead of steel bars in reinforced concrete members may lead to brittle failure. GFRP fibers were not completely ruptured after tension test while total strain values of GFRP bars are less than 5%. Yield strengths of steel bars were 125% of characteristic yield strength while tensile/yield ratio was 1.20. On the other hand, expected progressive necking on tension test was not being observed in steel bars. Brittle failure with 45^o was observed in steel bar specimens.
- According to the pull-out tension test results; development length was increased also adherence strengths were increased. Adherence strengths of GFRP bars are 85% of steel bars initially and this ratio was decreased to 80% approximately when the development length increased. Adherence strengths of GFRP bars are adequate although there was no ribbed part on the GFRP surfaces.

It has been concluded that using GFRP bars instead of steel bars in reinforced concrete buildings and members may create undesirable results. GFRP bars are not proper for bending so cannot be used as tie or hooked bars. GFRP bars can be used credibly in reinforced concrete slabs or road pavements in order to solve corrosion problems. However, it is recommended to investigate its behavior under other chemical influences, such as acid. In addition, the pH of the concrete is very high. It is recommended to investigate the effect of this alkaline environment on GFRP in the long term.

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