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Study of Compressive Behaviour of Glass Fiber Reinforced Polymer Concrete (GFRPC)

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ABSTRACT

In recent years, a lot of research has been done on the application of Fiber Reinforced Polymer (FRP) profiles filled with concrete for beams and columns. Among these materials are profiles made of glass fiber reinforced polymers (GFRP). Formwork and shear and flexural reinforcement are provided by GFRP box profiles in a new hybrid GFRP–concrete structural system. Additionally, GFRP box profiles strengthen hybrid materials and shield the concrete. The findings of an experimental research employing pultruded GFRP profiles filled with concrete are presented in this work. To investigate the compression behavior of the suggested hybrid GFRP-concrete materials, a number of compression tests were conducted. Three distinct strength classes of hybrid compression samples were created and put to the test. Comparing the hybrid material to reference samples, the results demonstrated a considerable improvement in compressive strength.

Keywords: Composite; Hybrid material; Concrete; GFRP; Compressive strength

1. INTRODUCTION

New materials are developed due to material-related problems and the demands of users. Researchers investigate new material types and applications and try to produce new designs to address to these problems and to satisfy these demands. In recent years, many researchers have concentrated on composite materials and hybrid designs, which can be considered as a derivative of these materials. Composite materials have required properties and are preferred in a wide variety of fields including the construction sector. Fiber Reinforced Plastic (FRP) composites are one of these composite types [1] These new generation composite materials have drawn considerable attention due to their superior mechanical strength, lightweight structure, high corrosion resistance and high resistance to chemicals, electric insulation, low density and high resistance/density ratio [2-5]. On the other hand, since these materials are not adequately known by the users and researchers, they have not yet replaced other materials. In fact, it is estimated that FRP composites can be a good solution for the majority of existing applications [6]. FRP composites are currently used to repair and renovate the existing buildings and to construct new ones; they have been used in aircrafts and space industry for more than 50 years [7-8].

New generation composites are not generally considered to be used as bearing systems in construction industry; they are preferred as secondary construction elements. However, today they are also used as main construction elements. Particularly due to increased mass production of FRP composites, they began to be more effectively used in buildings for different purposes and the use of lightweight fiber reinforced composite materials with high resistance began to be widely used in strengthening, repair and renovation in concrete buildings [9]. Most common uses of these types of composite materials in combination with concrete include strengthening buildings by wrapping FRP laminates in bottom surfaces of beams and wrapping FRP fabrics on the entire surface [10-14]. Their uses range from strengthening rod and beam elements to wrapping of columns for seismic improvement. Furthermore, they have a wider field of use including strengthening walls, beams, plates, composite flying bridges. Hybrid designs which use FRP composites in combination with traditional construction materials and systems entirely consisting of composite profiles [15].

2. EXPERIMENTAL STUDIES

Behavior of concrete and hybrid cube samples which were prepared at varying strengths (Figure 1) were analyzed in experimental studies. This sections contains two sub-chapters including material, which detailed the properties of GFRP-Concrete properties and compressive tests, which detailed experiment set-up.

Figure 1. Concrete and hybrid compression samples

Material

GFRP Profiles

Unit weight, fiber ratio and tensile properties of GFRP box profiles used in compressive tests were identified (Table 1). The samples were cut out from box profiles unit and specific weight tests were performed on the samples. Profile fiber ratios were determined using resin burning method [27]. Furthermore, modulus of elasticity and Poisson's ratios of GFRP materials were determined by tensile tests using related standards [28-30].

Table 1. Properties of GFRP

Unit Weight	1.75 g/cm^3		
Specific gravity	1.80		
Tensile Strength	560 N/mm^2		
Modulus of elasticity (E)	29000 N/mm^2		
Poisson Ratio	0.34		
Ratios Fiber of GFRP	Longitudinal	Felt	Matrix
(%)	41.6	8.8	49.6

The tests showed that GFRP had a unit weight of 1.75 g/cm^3 and specific weight of 1.80. Modulus of elasticity, tensile strength and Poisson's ratio values of GFRP were found to be 29000 N/mm^2, 560 N/mm^2 and 0.34 respectively. Sample tensile and Poisson's ratio graphs of GFRP box profiles are presented in Figure 2 and Figure 3.

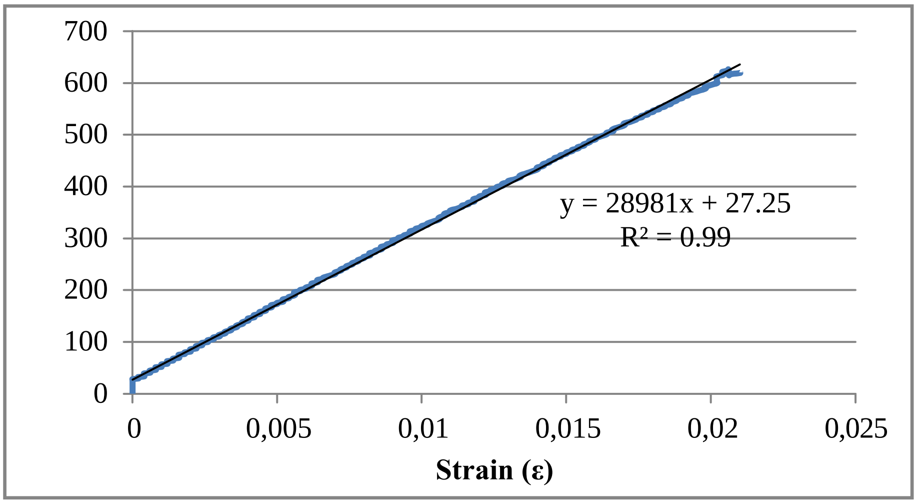

Figure 2. GFRP tensile chart

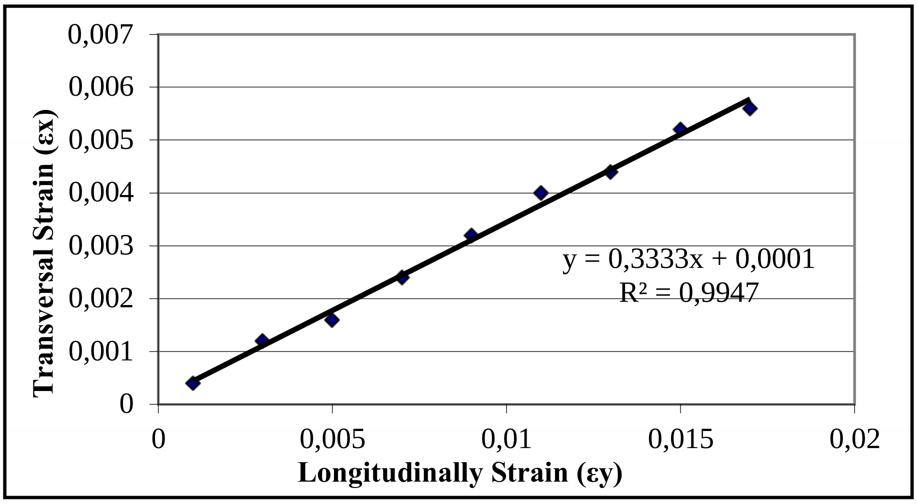

Figure 3. Poisson's ratio chart

Concrete

Mixture ratios in three different compressive strength classes were used to produce plain concrete and hybrid samples (Table 2). Only aggregate 1 was used as large aggregate to easily place the concrete inside GFRP profile.

Table 2. Mix proportions for 1 m^3 concrete

Material	**Strength Classes**		
(dm^3)	**I**	**II**	**III**
Aggregates I (5-12 mm)	379	381	382
Sand	336	338	339
Cement	105	111	119
Water	170	158	146
Plasticizer	-	2	4
Air	10	10	10
Total	1000	1000	1000

Fresh concrete was produced by mixing materials at defined ratios. Some of the mixture was placed in molds, while the rest was placed in GFRP box profiles. Hardened hybrid and plain concrete cube samples were cured [31 and 32] prepared for compressive tests. Hybrid samples which were produced as beams were cut into cube size at the end of curing procedure.

Compressive Tests

Compressive tests were performed on 100x100x100 mm hybrid and plain concrete samples at three different compressive strength classes (Figure 4). Wall thickness of GFRP box profiles is 6 mm. The results of the tests were evaluated and compared to the samples of the same type.

Figure 4. Compression samples

Test Setup

Computerized compression press with a capacity of 300 tons, digital displacement meter and data logger was used to measure the deformations in the material. Data logger had a total of 12 channels (4 and 8), can measure at the interval of ±10 volt and can record 8 data in a second. Digital displacement meter can measure at an interval of 0-50 mm and has a sensitivity of 0.01 mm (Figure 5).

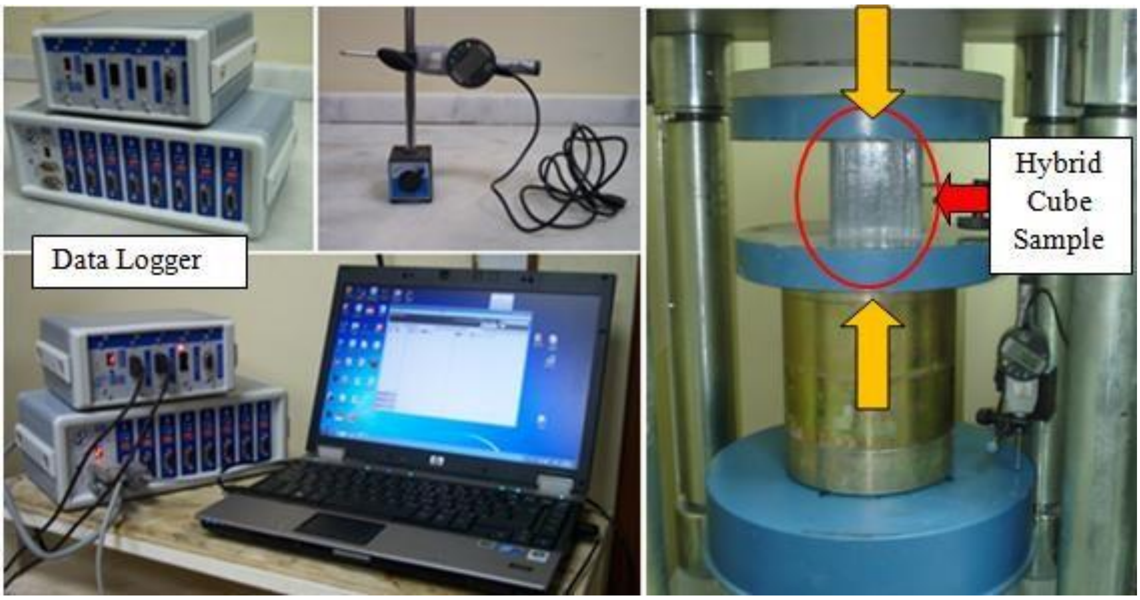

Figure 5. Test setup

3. RESULTS AND DISCUSSION

10 samples in each strength group, making a total of 30 plain concrete and hybrid cube

samples were tested and compared according to tensile unit deformation graphs. Firstly, fracture loads, compressive strength and unit weights of compression samples in I. strength class were calculated and presented in Table 3.

Mean fracture load of concrete samples in this strength class was found to be approximately 210000 N, compressive strength was found to be 19.13 MPa and unit weight value was found to be 2.30 g/cm^3.

Mean fracture load of hybrid samples was found to be 350000 N approximately, compressive strength was found to be 33.11 MPa and unit weight was found to be 2.22 g/cm^3. Comparison graph for the samples that represent the samples produced in I. strength class is presented in Figure 6.

Table 3. Compression test results in strength class I

Plain Concrete Compressive Test Results		
Sample	**Compressive Strength (MPa)**	**Unit Weight (g/cm^3)**
1	18.24	2.32
2	20.12	2.28
3	18.53	2.29
4	20.32	2.32
5	18.46	2.31
Average	**19.13**	**2.30**
Hybrid Compressive Test Results		
1	32.04	2.23
2	30.34	2.21
3	34.58	2.24
4	35.42	2.22
5	33.18	2.21
Average	**33.11**	**2.22**

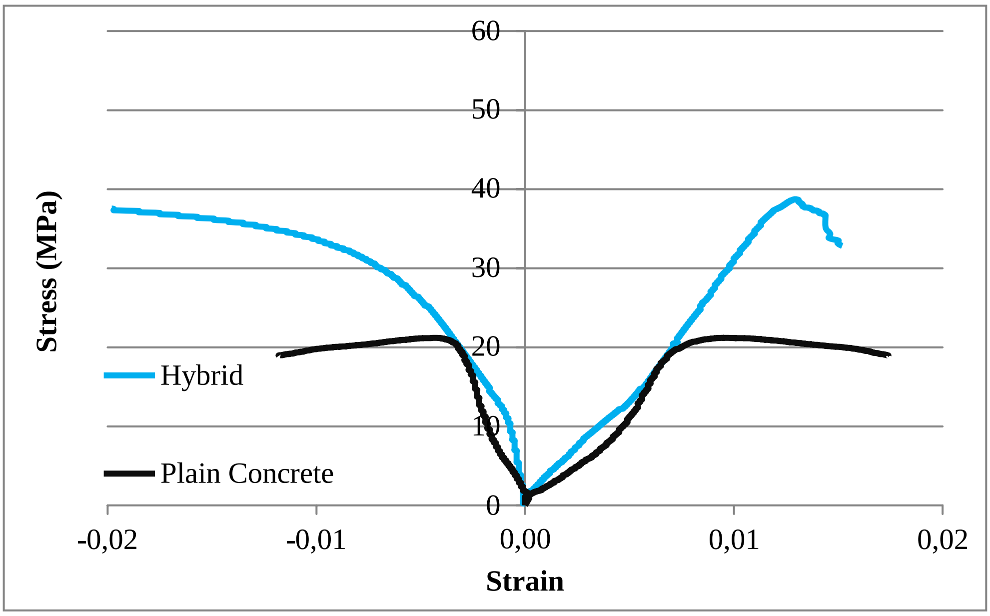

Figure 6. Comparison of stress-strain graphs in strength class I

The results showed that compressive strength of hybrid samples increased by 73% when compared to the plain concretes at the same cross sectional properties. While plain concrete cube samples had a unit deformation ratio of 1.7%; hybrid samples had a unit deformation ratio of 1.5%. Hybrid samples also function to protect the concrete, and serve as permanent mold and as an insulator. Plain concrete samples had a unit weight of 2.30 g/cm^3, while the hybrid samples had a unit weight of 2.22 g/cm^3. Thus, compressive strength of hybrid material increased, while its weight decreased by 4%.

Test results of the samples prepared in II. strength class are presented in Table 4.

Table 4. Compression test results in strength class II

Plain Concrete Compressive Test Results		
Sample	**Compressive Strength (Mpa)**	**Unit Weight (g/cm^3)**
1	26.84	2.31
2	28.53	2.35
3	28.05	2.32
4	30.64	2.29

5	29.28	2.32
Average	**28.67**	**2.32**
Hybrid Compressive Test Results		
1	43.58	2.24
2	47.16	2.21
3	44.25	2.24
4	42.37	2.23
5	46.26	2.23
Average	**44.72**	**2.23**

Mean fracture load, compressive strength and unit weight of plain concrete samples were found to be approximately 300000 N, 28.67 MPa and 2.32 g/cm^3 respectively. Mean fracture load value, compressive strength and unit weight values of hybrid samples were found to be approximately 460000 N, 44.72 MPa and 2.23 g/cm^3 respectively. Comparison graph for the samples in II. strength class are presented in Figure 7.

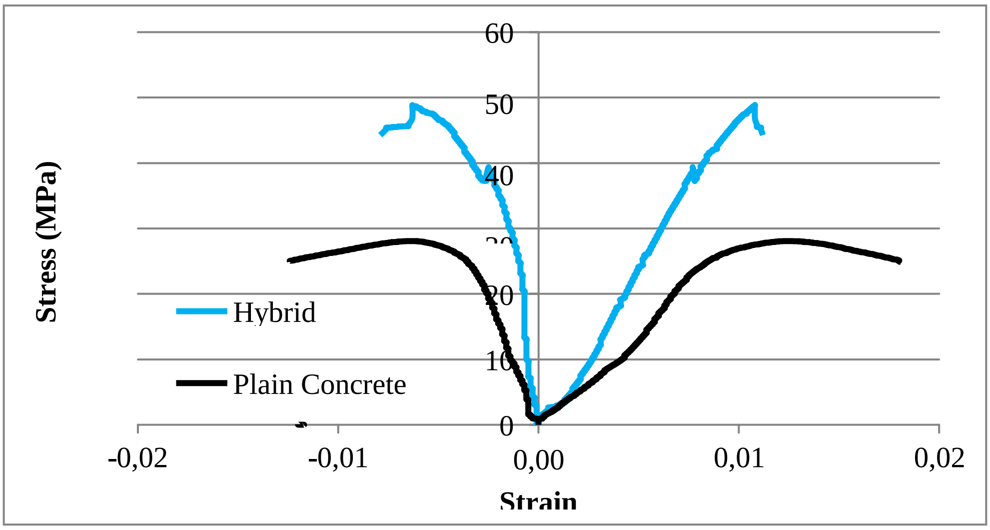

Figure 7. Comparison of stress-strain graphs in strength class II

Plain concrete cube samples in II. strength class had a unit deformation value of 1.5%; while hybrid samples had a unit deformation value of 1.0%. As the strength increased, the material became brittle.

Based on these results, compressive strength of hybrid samples increased by 56% when compared to that of plain concrete samples. It was found that plain concrete samples and hybrid samples had a unit weight of 2.32 g/cm^3 and 2.23 g/cm^3 respectively. Thus, compressive strength of the material increased, however its weight decreased by 4%.Compressive test results of the samples in III. strength class are presented in Table 5.

Tablo 5. Compression test results in strength class III

Plain Concrete Compressive Test Results		
Sample	**Compressive Strength (MPa)**	**Unit Weight (g/cm^3)**
1	42.67	2.38
2	43.38	2.36
3	42.82	2.34
4	39.96	2.35
5	44.64	2.35
Average	**42.69**	**2.36**
Hybrid Compressive Test Results		
1	50.37	2.26
2	51.18	2.25
3	52.53	2.25
4	49.32	2.26
5	53.18	2.28
Average	**51.32**	**2.26**

It was found that fracture load, compressive strength and unit weight values of plain concrete samples were 420000 N, 42.69 MPa and 2.36 g/cm^3 respectively. On the other hand, fracture load, compressive strength and unit weight values of hybrid samples were found to be 510000 N, 51.32 MPa and 2.26 g/cm^3 respectively. Tensile-unit deformation graph which represents hybrid and concrete samples in III. strength class are presented in Figure 8.

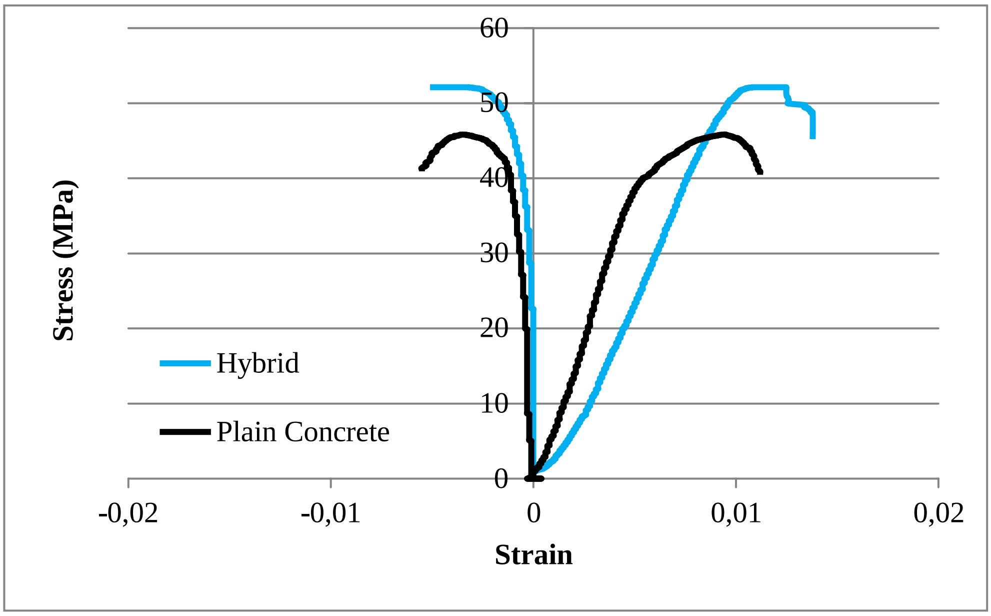

Figure 8. Comparison of stress-strain graphs in strength class III

Compressive strength of hybrid samples increased by 20% when compared to that of plain concrete samples. It was found that as strength class of plain concrete samples increased, deformation decreased. While concrete samples had a unit weight of 2.36 g/cm^3, this value was found to be 2.26 g/cm^3 in hybrid samples. Compressive strength of the material increased by 20% and the weight of the material decreased by 5%.

The ductility is decreased while the concrete strength class is increased in all specimens. The graph showing compressive strength increase in hybrid and plain concrete samples at all strength classes is presented in Figure 9. It is understood from the graph that in all compressive strength types, hybrid samples reached higher compressive strength values than those of plain concrete samples at a higher strength class. GFRP profiles do not allow the concrete lateral displacement thus the compressive strength of hybrid samples are greatly increased.

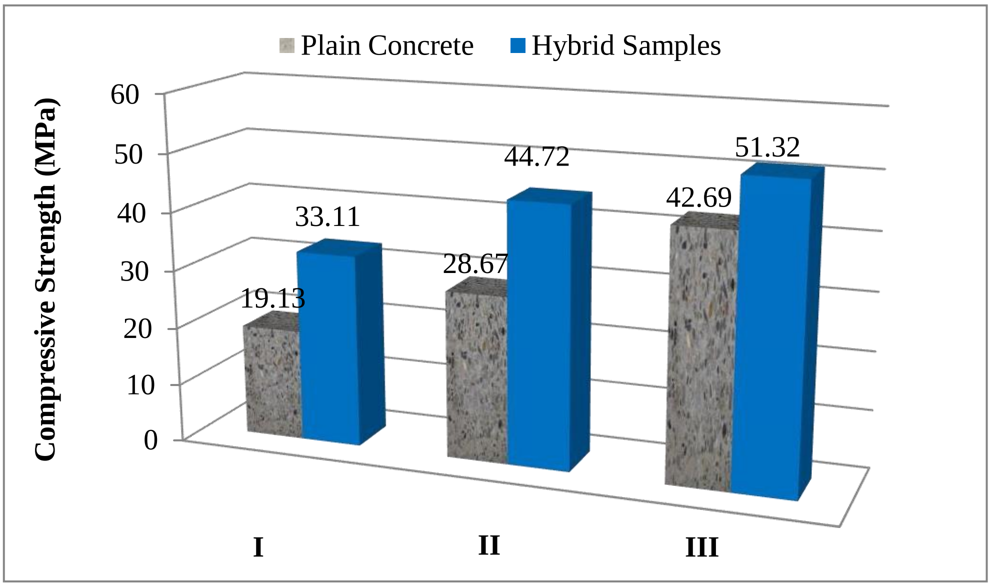

Figure 9. Comparison of compressive strength

Analysis of the samples in all strength classes showed that as compressive strength class increased, strength difference between hybrid and plain concrete samples decreased (Figure 10). It was found that in samples with a mean compressive strength of 22 MPa, increase rate started from 75% level in hybrid samples when compared to plain concrete samples. We found that as strength class increased, increase rate decreased. An increase of 20% occurred at 43 MPa strength. As concrete compressive strength increased, GFRP profile effect in hybrid samples decreased.

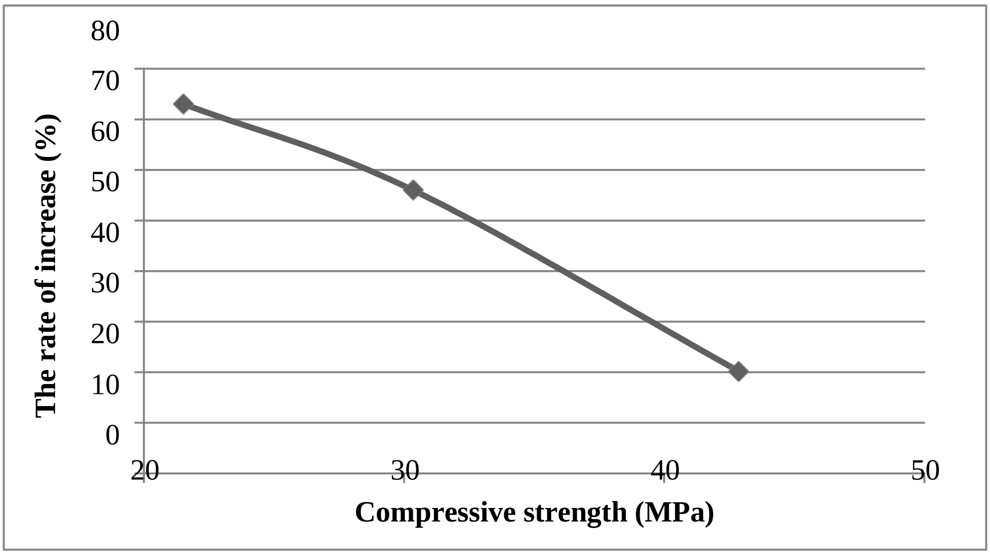

Figure 10. The rates of strength difference in compressive strength

Typical failures of the hybrid samples are shown in Fig. 11. In all specimens, failure resulted from the rupture of the GFRP profiles corner. GFRP profiles were deformed from lateral fibers.

Figure 11. Failure modes of hybrid samples

GFRP profile make up of 14.80 cm^2 of total cross section area in hybrid samples. A compressive strength increase of 20-73% occurred in design of hybrid materials when compared to plain concrete samples. This increase was obtained by 14.8% GFRP profile in cross-section area. On the other hand, the tests showed that GFRP profiles deformed in felt fibers.

4. CONCLUSIONS

The results of this study, which analyzed the behavior of hybrid construction material which used a combination of concrete and GFRP box profiles under compressive strength, are summarized below:

- GFRP profiles have the potential to solve various material related problems in construction sector due to their lightweight structure, high corrosion and tensile strength.
- In hybrid design, since GFRP box profiles serve as formwork, there is no need for a second

formwork element to form the concrete. GFRP profiles protect the concrete by preventing exterior water and humidity entrance and significantly contribute to concrete curing.

- In compression tests, it was found that compressive strength of hybrid samples in I. strength class increased by 74% when compared to those of plain concrete samples which had the same cross-section properties. This increase was found to be 52% in II. strength class and 20% in III. strength class.
- It was found that as compressive strength class increased, the strength difference between hybrid and plain concrete cube samples decreased. While increase ratio of hybrid samples was 74% when compared to plain concrete samples at low strengths, as strength class increased, increase ratio decreased. Increase ratio decreased to 20% at 43 MPa. As concrete compressive strength increased, the effect of GFRP profile in hybrid samples decreased.
- In all strength classes, while compressive strength of hybrid samples increased when compared to plain concretes, the weight of hybrid cube samples decreased by 5% when compared to plain concretes.
- The new hybrid material has a potential to solve the problems of durability and corrosion especially in marine buildings as an independent structure in addition to its high tensile and compressive strength. Furthermore, GFRP-Concrete hybrid construction elements can be used in buildings such as chemical production plants, bridge beams and jetties.
- GFRP profiles deformed in widthwise felt fibers in all tests conducted within the scope of the study. It is foreseen that increasing the ratio of widthwise felt fibers and decreasing lengthwise felt fibers in production process will yield positive results in terms of cost and strength.

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