An Investigation of Concrete Strength of Hybrid Construction Materials Under the Effect of Heat

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Abstract. The hybrid use of concrete and Glass Fiber Reinforced Plastic (GFRP) profiles in construction material technologies in recent years offers many new opportunities. Filling fresh concrete into GFRP profile allows for obtaining superior advantages compared to component materials. The purpose of this study is to investigate the change in the strength of concrete in hybrid material exposed to high temperatures. To this end, hybrid compressive samples were prepared by filling GFRP composite box profiles with concrete and plain concrete samples were prepared for comparison. The cubic samples were exposed to high temperatures at 25–200–400–600–800 °C. Strength losses of the plain concrete and the concrete in the hybrid material, which had the same dimensions, under the effect of heat were determined.

Keywords: GFRP · Concrete · Heat · Hybrid materials
Compressive strength

1 Introduction

In recent years, Fiber Reinforced Plastic (FRP) composites, which are increasingly used as building materials, have many positive qualities. These materials are popular especially due to their corrosion performance, lightness and high tensile strength and can be produced in different fiber types. These materials are primarily produced as fabric to strengthen structures, as column or beam to be used as support components and finally as FRP reinforcement material to be used instead of steel reinforcement. Among FRPs, the use of GFRP composites in the form of profile is more common compared to other fiber types due to their inexpensiveness.

The subject of hybrid construction components prepared by filling FRP profiles or pipes with concrete attracts the interest of many researchers and several studies have been conducted on the subject in recent years [1–6]. Scientific studies show that researchers will focus on the hybrid use of traditional construction materials and FRP composites in the upcoming years [7]. Many studies have shown that the hybrid use of FRP composites and traditional materials such as concrete offers solutions to eliminate certain disadvantages of construction materials manufactured solely from FRP [8–11].

The use of concrete within FRP profiles presents many advantages such as area reduction, rigidity, increased strength, prevention of local fractures, improved curing

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and permeability. Hybrid use may mitigate or completely eliminate the disadvantage arising from the concrete or the GFRP profile. In the traditional concrete production, forming small parts in order to prepare the mold takes a lot of time and causes additional costs. In the hybrid system, on the other hand, a second mold component is not required since the GFRP box profile serves as a mold. Thus, the hybrid system allows for saving time and reducing mold costs largely and this property referred to as permanent form [12–19] in the literature provides great convenience.

Also, regional and local fractures occur in GFRP profiles due to bending [20, 21]. Since GFRP profiles are filled with hardened concrete, these local fractures are reduced. Thus, the hybrid material is expected to show a better performance under bending loads. GFRP box profiles do not let external water and moisture in and also prevent the concrete with plastic consistency in the profile from losing its water and moisture, thus provide great advantages for this operation which is vital for the curing of concrete. In this way, the hydration process of the concrete, which is desired to be cured at 100% relative humidity for 28 days, is completed without any issues [21]. Other advantages of GFRP profiles include good impermeability and water-moisture insulation, allowing for production of construction components with smaller dimensions compared to component materials and increased strength and rigidity values.

Apart from these advantages, the purpose of this study is to determine the effect of GFRP profiles, which protects the concrete in hybrid system against external effects and shows high performance particularly against tensile stresses, on the strength of concrete in case of high temperature or fire.

2 Experimental Studies

Concrete, which is a basic construction material, is only used against compressive stresses in material design since it is quite weak against tensile and bending stresses. GFRP composite material, on the other hand, stands out with its high tensile strength. In the hybrid material design produced by filling GFRP box profile with concrete, concrete is expected to handle compressive stresses and GFRP is expected to handle tensile stresses.

This study examines differences in compressive strength of the concrete in hybrid material caused by high temperature. The room temperature was accepted as the reference point and compressive samples kept at 200–400–600–800 °C were tested to calculate weight loss and compressive strength values under the effect of heat.

2.1 Materials and Method

The effects of the hybrid use of concrete in GFRP box profiles having the same dimensions on heat deformation of concrete were investigated experimentally. To this end, plain concrete samples and hybrid samples were produced by filling GFRP box profiles having the same dimensions with fresh concrete. In axial compression tests, plain concrete samples were tested by exposing the samples to temperatures of 25–200–400–600–800 °C, whereas hybrid samples were tested by exposing the samples to same temperatures, taking the concrete in the GFRP profile out and then applying the compression test. Thus, the changes in compressive strength of profile concrete and concrete taken out from GFRP profile were determined after axial compression tests.

The GFRP box profile had the dimensions of 5 × 74 × 74 mm (Fig. 1). Mechanical and physical properties of the GFRP box profile determined as a result of the tests can be seen in Table 1.

Fig. 1. GFRP box profiles

Table 1. Properties of GFRP box profile

Properties	Values
Specific gravity	1.80
Unit weight	1.78 g/cm^3
Tensile strength	550 MPa
Modulus of elasticity (E)	30,000 MPa

Table 2 shows the components of the concrete, which was produced in a single strength class according to TS 802 [22] using only sand and crushed stone grade 1.

Table 2. Concrete mix design

Material	Volume (dm^3)
Aggregates I (5–12 mm)	379
Sand	336
Cement	105
Water	170
Air	10
Total	1000

Hybrid materials were prepared together with the plain concrete in a single strength class. The concrete with plastic consistency was filled in 74 mm cubic molds and the remaining was filled in GFRP box profile. All samples were kept at 23 °C for 28 days for curing. Then, open parts of the hybrid samples were closed using the same material. Hybrid and plain concrete cubes before and after the effect of heat can be seen in Fig. 2.

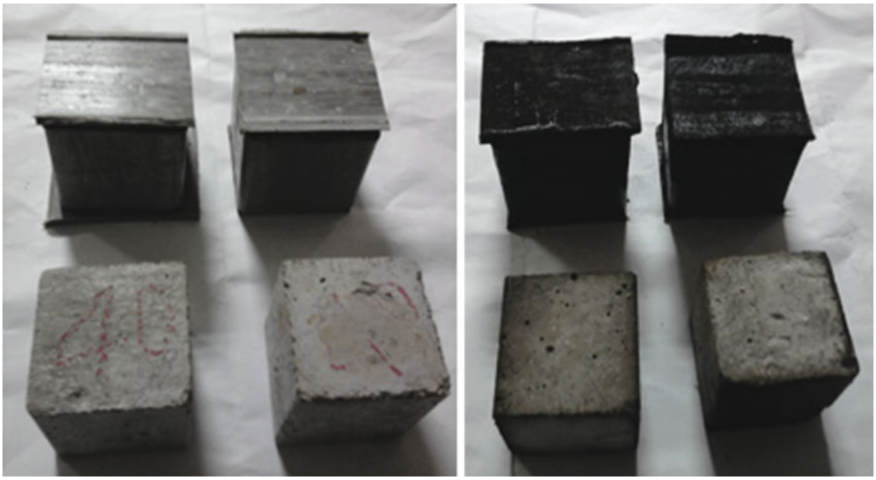

Fig. 2. Before and after the heat effect of the samples

Figure 3 shows the exposure of the cubic samples to heat in the furnace and Fig. 4 shows the concrete compressive samples.

Fig. 3. Samples exposed to high temperature in furnace

Fig. 4. Concrete samples

Compression tests were applied to plain concrete and concrete in hybrid samples exposed to different temperatures including the room temperature (Fig. 5).

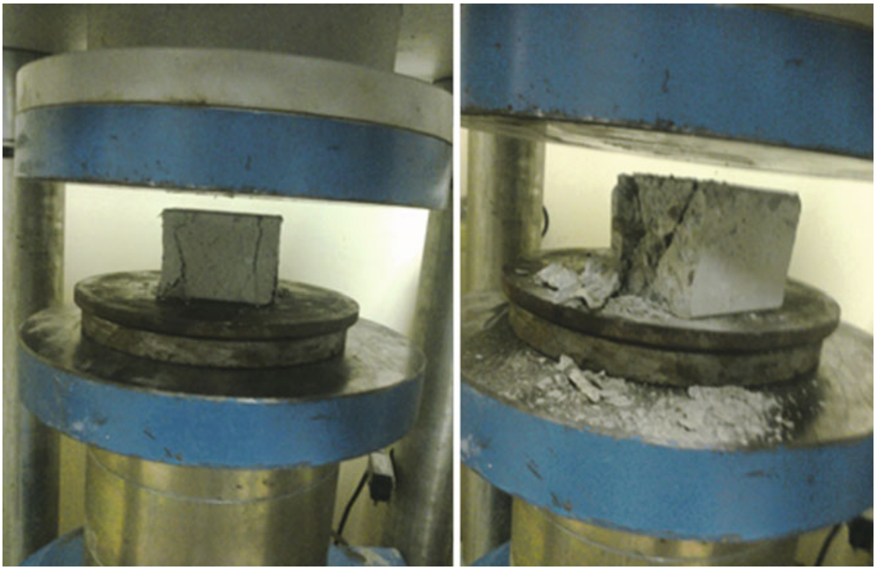

Fig. 5. Breaking of the samples

2.2 Test Results

Compression tests were performed after heating plain concrete and hybrid samples up to temperatures of 25–200–400–600–800 °C. Weight and strength losses after the performance of the tests were determined. Table 3 shows the results of the compression test performed at room temperature, which was accepted as the reference point.

Table 3. Compressive strength (25 °C)

Sample	Compressive strength (kg/cm^2)
1	278.65
2	220.08
3	268.03
Average	255.58

The average compressive strength was found to be 255.58 kg/cm^2 in tests performed at room temperature, approximately 25 °C.

Table 4 shows weight losses and Table 5 shows compressive strengths of plain concrete and concrete in hybrid samples at 200 °C.

Table 4. Weight Losses (200 °C)

Sample	Hibrit (%)	Plain (%)
1	1.41	1.65
2	0.31	1.55
3	1.11	1.84
Average	0.94	1.68

Table 5. Compressive strength (200 °C)

Sample	Hybrid (kg/cm^2)	Plain concrete (kg/cm^2)
1	248.98	267.46
2	230.76	276.32
3	298.46	269.75
Average	259.40	271.17

The weight loss of concrete in hybrid samples exposed to 200 °C was 0.94% and the compressive strength was 259.40 kg/cm^2. These values were 1.68% and 271.17 kg/cm^2 for plain concrete. Compared to the reference concrete, no strength loss occurred in both plain concrete and hybrid samples. In contrast, slight increases were observed due to hot curing (Fig. 6).

Table 6 shows weight losses and Table 7 shows compressive strengths of samples exposed to 400 °C.

The weight loss was 7.66% for concrete in hybrid samples and 7.13% for plain concrete at 400 °C. Compared to 200 °C, the weight loss increased 8 times for plain concrete and 4 times for hybrid samples. The compressive strength of concrete in hybrid samples was 304.60 kg/cm^2 and the compressive strength of plain concrete was 250.62 kg/cm^2. The comparison with the reference concrete at room temperature can be seen in Fig. 7. Compared to the reference concrete, the strength loss was 2% for plain concrete and the increase in strength was 19% for concrete in hybrid samples at 200 °C.

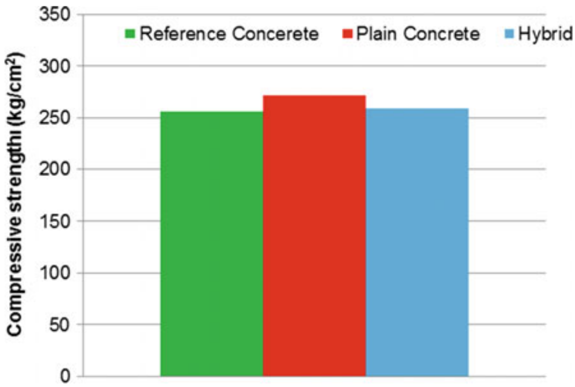

Fig. 6. Comparison of compressive strengths (200 °C)

Table 6. Weight losses (400 °C)

Sample	Hybrid (%)	Plain (%)
1	11.48	6.91
2	4.97	7.33
3	6.53	7.14
Average	7.66	7.13

Table 7. Compressive strength (400 °C)

Sample	Hybrid (kg/cm^2)	Plain concrete (kg/cm^2)
1	279.34	255.78
2	302.63	286.65
3	331.82	209.42
Average	304.60	250.62

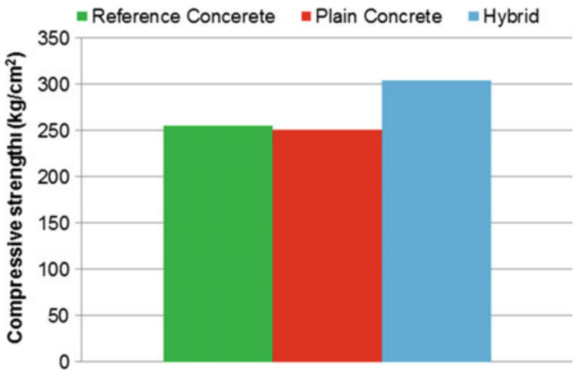

Fig. 7. Comparison of compressive strengths (400 °C)

The GFRP profile on the sample surface was deformed in hybrid material after keeping the sample in the furnace at 400 °C for 1 h, but the profile managed to protect the concrete inside (Fig. 8).

Fig. 8. Samples after 400 °C heat

The temperature was raised to 600 °C during experiments and weight loss values shown in Table 8 and compressive strength values shown in Table 9 were obtained. With the increase in the temperature, the GFRP profile completely was deformed, the matrix of the profile burned and only glass fibers remained. Thus, the weight loss value was calculated only for plain concrete samples due to deformed surface in hybrid samples (Fig. 9).

Table 8. Weight losses (600 °C)

Sample	Plain (%) 600 °C
1	8.08
2	8.74
3	8.12
Average	8.31

Table 9. Compressive strength (600 °C)

Sample	Hybrid (kg/cm^2)	Plain concrete (kg/cm^2)
1	257.78	210.58
2	229.72	222.22
3	227.27	234.81
Average	238.25	222.53

Fig. 9. Samples after 600 °C heat

The weight loss of plain concrete was 8.31% at 600 °C. The weight loss at 600 °C increased approximately 5 times compared to the weight loss at 200 °C.

After exposure to 600 °C, the compressive strength of concrete in hybrid samples was 238.25 kg/cm^2 and the compressive strength of plain concrete was 222.53 kg/cm^2. The strength loss rate increased for plain concrete samples with increasing temperature (Fig. 10). The strength loss of concrete in hybrid samples was about 7% at 600 °C, whereas this value was 13% for plain concrete.

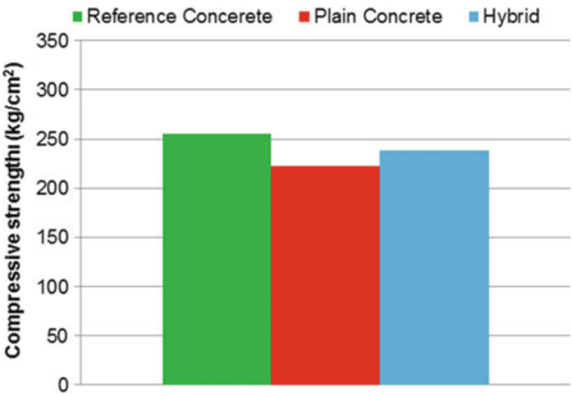

Fig. 10. Comparison of compressive strengths (600 °C)

The temperature was raised to 800 °C and weight loss values shown in Table 10 and compressive strength values shown in Table 11 were obtained. Figure 11 shows the final state of materials once the temperature reached 800 °C. GFRP profile matrix completely burned and only glass fibers remained. Considerable losses were observed in both plain concrete and hybrid samples since the concrete was no longer protected at high temperatures (Fig. 11).

Table 10. Weight losses (800 °C)

Sample	Plain (%) 800 °C
1	7.68
2	10.84
3	10.45
Average	9.66

Table 11. Compressive strength (800 °C)

Sample	Hybrid (kg/cm^2)	Plain concrete (kg/cm^2)
1	142.66	164.03
2	139.47	140.04
3	146.01	149.73
Average	142.71	151.26

Fig. 11. Samples after 800 °C heat

The weight loss of plain concrete was found to be 9.66% at 800 °C. The weight loss at 400 °C increased approximately 6 times compared to the weight loss at 200 °C.

After the effect of heat at 800 °C, the compressive strength of concrete in hybrid samples was 142.71 kg/cm^2 and the compressive strength of plain concrete was 151.26 kg/cm^2. The comparison between strength values of plain concrete and concrete in hybrid samples can be seen in Fig. 12.

Compared to the reference concrete, the strength loss of plain concrete was found to be 44% at 800 °C. This rate was 44% for hybrid samples. Thus, it should be considered that the concrete exposed to 800 °C may lose almost half of its strength.

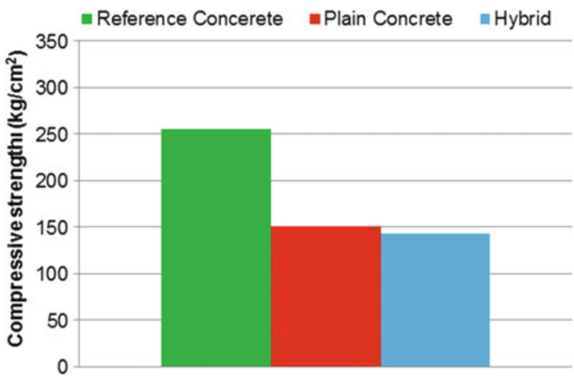

Fig. 12. Comparison of compressive strengths (800 °C)

A slight increase in strength was observed for plain concrete at 200 °C compared to room temperature due to the effect of curing. The compressive strength continued to decrease with increasing temperature. For hybrid samples, the effect of curing was evident at 400 °C and the compressive strength increased. With increasing temperature and burning of the GFRP profile, the concrete lost its protection and considerable strength losses were observed (Fig. 13). The critical temperature value was found to be 200 °C for plain concrete and 400 °C for concrete in hybrid samples. Strength losses increasingly continued after the temperature values mentioned.

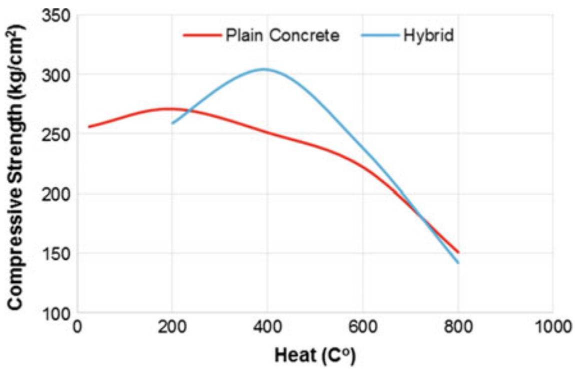

Fig. 13. Decrease in strength under heat effect

3 Conclusions and Recommendations

The results obtained in this study investigating the compressive behavior of hybrid compressive components formed by filling square-shaped GFRP box profiles with concrete at high temperatures are summarized below:

- The weight loss of concrete in hybrid samples was calculated to be 0.94% at 200 °C and 7.66% at 400 °C. The weight loss of concrete in hybrid samples at 400 °C increased approximately 8 times compared to the weight loss at 200 °C.
- The weigh loss of plain concrete was 1.68% at 200 °C, 7.13% at 400 °C, 8.31% at 600 °C and 9.66% at 800 °C. The weight loss increased with increasing temperature as expected. Compared to the weight loss at 200 °C, plain concrete's weight loss increased 4.2 times at 400 °C, 5 times at 600 °C and 5.7 times at 800 °C.
- The average compressive strength of the reference concrete was 255.58 kg/cm^2. Plain concrete's compressive strength was 271.17 kg/cm^2 at 200 °C, 250.38 kg/cm^2 at 400 °C, 222.53 kg/cm^2 at 600 °C and 151.26 kg/cm^2 at 800 °C. The strength loss in plain concrete was 13% at 600 °C and 41% at 800 °C.
- The hybrid material's average compressive strength was 259.40 kg/cm^2 at 200 °C, 304.60 kg/cm^2 at 400 °C, 238.25 kg/cm^2 at 600 °C and 142.71 kg/cm^2 at 800 °C. The strength loss of concrete in hybrid samples was about 7% at 600 °C. Compared to the reference concrete, the strength loss of concrete in hybrid samples was 44% at 800 °C.
- It was determined that GFRP profile matrix completely burned at temperatures over 400 °C and only glass fibers remained. The concrete was no longer protected in hybrid samples once the temperature reached 800 °C. Considerable losses were observed in both plain concrete and hybrid samples since the concrete was no longer protected at high temperatures.
- The critical temperature value at which plain concrete started to lose strength was 200 °C, whereas this value was 400 °C for hybrid samples. GFRP profile delays the strength loss of concrete at low temperatures. Similar strength losses are observed for both concrete types at temperatures over 400 °C.

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