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Effects of glass fiber reinforced polymer pipe waste powder usage on concrete properties

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Abstract: In this study, the recycling of pipe waste powder in concrete has been experimentally investigated to reduce its harm to the environment and human health. Glass fiber reinforced polymer pipe waste powder (GFRP-WP) reveals during the production of additional coupling and bends of GFRP pipes produced for clean water and wastewater systems. GFRP-WP is composed of polyester resin, sand, and E-glass fiber. GFRP-WP was used as a partial replacement to fine aggregate in proportions of 0% 5%, 10%, 20%, 30% and 40% to the concrete mixture. The effect of GFRP-WP was examined on the physical and mechanical properties of concrete, such as compressive strength, workability, capillarity, and water absorption. According to the results, it was seen that GFRP-WP could be used as filler in concrete, and some positive and negative effects on concrete were also determined. GFRP-WP reduced the workability of concrete. Therefore, GFRP-WP impaired the properties of the concrete if certain mixing ratios were exceeded. It was determined that GFRP-WP could be used in concrete up to 15% by volume as a partial replacement for fine aggregate.

Keywords: GFRP, pipe, recycling, waste powder, workability.

1. Introduction

Nowadays, advances in technology and industrialization cause critical environmental problems. The problem, called waste material, disrupts the natural balance and causes storage problems and environmental pollution. Waste materials are glass, metal, paper/cardboard, marble powder, plastic, various industry by-products (fly ash, blast furnace slag, silica fume), etc. The recycling or recovery of different waste materials is an issue that researchers have been working on for many years (Guo et al., 2020; Jain, et al., 2020; Castro et al., 2014; Meng et al., 2018; Silva et al., 2020; Sologa et al., 2014; Yazdanbakhsh et al., 2018; Yurt, 2020). As industrial wastes are increasing rapidly, it has become necessary to use them through recycling and recovery. It has also become a preference due to the benefits they provide to the products they are added to. Studies on improving the properties of concrete almost date back to the years when concrete production started. In this initial process, efforts to enhance concrete performance were tried to be achieved by developing natural components in its internal structure. However, in recent years, it has become widespread with the researchers' investigation on the reusability of both natural components of concrete and various industrial by-products or substances that are harmful to human health and disrupt the environment and natural balance. Studies on using waste powder or waste materials as filler material in concrete after being pulverized have shown a positive effect on the properties of concrete such as compressive strength, tensile strength, reduction of void ratio, and workability regulation (Aydin & Saribiyik, 2013; Beycioğlu et al., 2020; Bisht & Ramana, 2018; Corinaldesi el al., 2005; De Castro & De Brito, 2013; Dobiszewska & Beycioğlu, 2020; Erek et al., 2002; Evram et al., 2020; Khodabakhshian et al., 2018; Xiao et al., 2020). For instance, in the study by Bhushan et al. (2019), it was emphasized that a concrete mixture containing 18% glass powder and 40% marble dust can be used effectively in structures designed for compressive strength (Bhushan et al., 2019). In the study conducted by Saribiyik et al. (2013), it was stated that using glass waste powder instead of quartz powder in polymer concrete has a positive effect on the workability of polymer concrete, reducing segregation, improving pressure and flexural strength (Saribiyik et al., 2013). Xiao et al. 2020 stated that the recycling of waste glass has great potential as the raw material of geopolymer cement (Xiao et al., 2020).

In the study conducted by Khodabakhshian et al. (2018), it was stated that about 10% of marble waste powder improves the compressive strength of concrete but decreases the workability (Khodabakhshian et al., 2018). In the study conducted by Aliye et al. (2020), they suggested a suitable mixing ratio for the ceramic waste powder to regulate the workability of concrete (Evram et al., 2020). It was stated that up to 21% waste glass replacement rate as fine aggregate in concrete increases the microstructure quality of the concrete (Bisht & Ramana, 2018). It was stated that waste glasses cause detrimental effects on concrete properties due to smooth particle surfaces and harmful alkali-silica reaction (Corinaldesi et al., 2005; De Castro & De Brito, 2013).

Fiber reinforced polymer (FRP) composites are produced in various forms using different fiber types as reinforcement. The projected demand for FRP composites is expected to increase by 10-15 (Billion USD) in the next two decades. Unfortunately, waste materials generated before and after (with the end of service life) composite material production are in large quantities, causing them to be sent to landfills for disposal (Bhadra et al., 2017; Oliveux et al., 2015; Witik et al., 2013). Therefore, various levels of waste material arise during the production process of FRP composites and when they complete their service life in sectors such as construction, aviation, and automobile. Many researches have been done on the recycling of FRP waste materials and their disposal by using them in different materials (Asokan et al., 2010, 2009; Bağriaçik et al., 2021; Bağrıaçık et al., 2020; Beycioğlu et al., 2020; Cestari et al., 2018; Clark et al., 2020; Dehghan et al., 2017; Farinha, de Brito, & Veiga, 2019; Osmani & Pappu, 2010; Özüyağli et al., 2016; Ribeiro et al., 2013; Saikia & De Brito, 2012). For example, in the review study on the use of plastic waste materials in concrete, it was stated that plastic affects the workability depending on the geometry of the aggregate, and the compressive strength value of the concrete decreases as the amount of plastic increases (Saikia & De Brito, 2012). In the study on the transformation of carbon and glass fiber polymer matrix composite waste into cement-based materials, the performance of 6% glass and carbon FRP waste material compared to cement was investigated in abrasive environment conditions, and it was concluded that it could be used as a cement additive (Clark et al., 2020). In the study on the evaluation of the reuse of GFRP waste as a filler in cement mortars, it was stated that GFRP waste improves the workability of mortars and reduces density and the mortar using 50% GFRP waste instead of natural aggregate had the best technical performance (Farinha et al., 2019). Asokan et al. (2009) used GFRP waste powder in concrete at a 5-50% rate as a partial replacement for fine aggregates by fixing the cement amount and workability.

They found that concrete compressive strength decreased by 22% -60%, respectively, as the rate of waste material increased (Asokan et al., 2009). Asokan et al. (2010) added 5% to 15% of the GFRP waste specimen to the mixture using a 2% superplasticizer. The developed concrete composites significantly improved compressive strength and flexural strength shrinkage, initial surface absorption, total water absorption, and density. Also, they stated that it was suitable for regular use. They also noted that the quality of concrete composite products depends on GFRP waste material properties, particle size distribution, and aggregate mixing ratio, additive concentration, grinding process, and grinding degree. However, they also recommended further studies to evaluate the long-term durability of GFRP waste powder added concrete (Asokan et al., 2010). When the literature is examined, the results of studies on recycling waste materials in different types of basic materials give a good idea. However, since waste types have unique properties such as content, geometry, and component, it is understood that more studies are needed to determine how the waste affects the main material properties and to determine the recycling recipe. One of these wastes is GFRP composite pipe waste produced by the glass fiber winding method. GFRP pipes are produced by fiber winding method using quartz sand, glass fiber, and polyester resins. GFRP pipe wastes consist of non-standard parts of GFRP pipes during the production phase, powder revealed during the cutting of pipes and preparation of joints, and pipes out of service after use. These waste materials are crushed and destroyed by burning in the rotary kilns of cement factories located in the region. This brings additional costs to the company due to the fees paid for the transport and disposal of waste material to the cement factory. It is also known that the polymer gas generated during the burning of the waste in the rotary kiln is harmful to the environment. Therefore, the recovery of this waste material by using it as filler material in the traditional concretes, which are most commonly produced today, is essential in waste disposal.

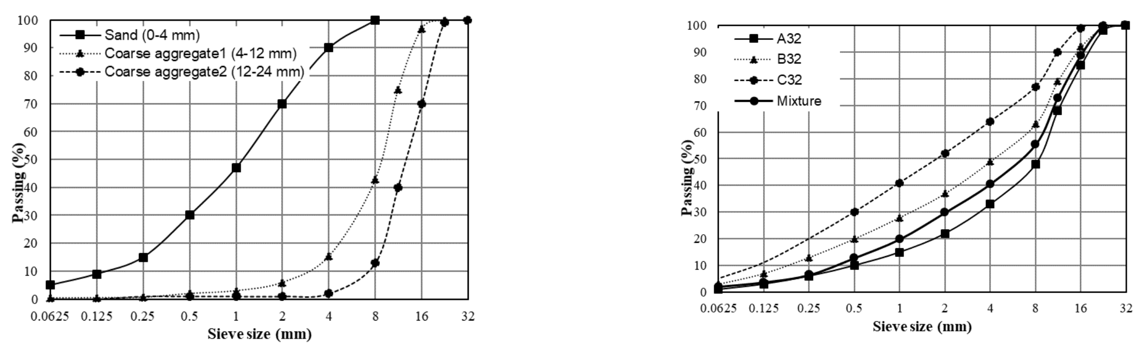
In this study, the waste powder usability revealed during the production of GFRP pipes during the cutting of the pipes and the arrangement of the additional couplings in concretes compared to fine aggregate was investigated. In concrete produced by adding GFRP-WP to the mixture in certain proportions as a percentage of fine aggregate (0-4 mm), the effect of workability in a fresh state and compressive strength, water absorption by weight and volume, and capillarity properties in the hardened state was studied to determine the waste rates suitable for use in concrete. Using GFRP-WP in concrete aims to eliminate waste disposal costs, make concrete more economical, and improve the physical and mechanical properties of concrete.

2. Materials and methods (indent every subtitle - left 0.42 cm)

2.1. *Materials*

2.1.1. Concrete materials

In this study, concrete specimens consist of fine aggregate with 0-4 mm sieve opening (Natural river sand), coarse aggregates with 4 -12 mm and 12-24 mm sieve opening where Petrographic structure was Marmara fragmentation, CEM I 42.5 R cement, drinking water, and GFRP-WP and plasticizer additive. Experiments were performed materials laboratory of Civil Engineering, Sakarya University of Apply Sciences. According to the material tests carried out in the laboratory, the saturated dry surface-specific gravity of sand and coarse aggregates were 2.70, 2.68 kg /dm3, respectively. The specific gravity of the cement was found to be 3.15 kg / dm3. Sieve analysis was made on the aggregates according to the Standard (TS 706 EN 12620+A1, 2009) (Figure 1a.), and the mixing ratios of sand and coarse aggregate1 and coarse aggregate2 were selected as 40%, 25% and 35%, respectively. The sieve analysis results of sand, and coarse aggregates (Figure 1a.) and the sieve limits according to the standard are illustrated in Figure 1b.



(a) (b)

Figure 1. Results of the sieve analysis (a) granulometry curve of the aggregates; (b) mixture granulometry curve.

2.1.2. GFRP pipe waste powder

GFRP-WP, which was revealed in the production of additional sleeves of GFRP pipes produced for clean and wastewater transport and production of specially produced bends, was used in the study. GFRP-WP was provided from Subor GFRP pipe factory in Sakarya, Turkey. The wet pulp (Figure 2a) and dry forms (Figure 2b) of GFRP-WP stocked as wet pulp are shown in Figure 2. GFRP pipes are produced with polyester resin, quartz sand, glass fiber roving. According to the information taken from the product catalog of the materials used in GFRP pipe manufacturing; Polyester resin is of Density: 1.10 g/cm3, Tensile strength: 75 MPa, Tensile Modules: 3700 MPa, Glass fiber is of Type: E-glass, roving density: 2400 g/km, filament diameter: 11-17 □m, the chemical content of quartz sand is SiO2: 98.6%, CaO + MgO: 0.75%, Fe2O3: 0.303, Al2O3: 0.491%.

(a) (b)

Figure 2. GFRP-WP a) pulp form; b) dry form.

The scanning electron microscopy (SEM) image of GFRP-WP is illustrated in Figure 3. Micro Glass fibers, resin, and sand particles in the content of GFRP-WP can be seen from the SEM photograph. The EDX spectrums and chemical compositions of the particles are obtained from the points marked with 1 and 2 in Figure 3. The EDX spectrums and chemical compositions of the particles are presented in Figure 4 and Figure 5. From the EDX analysis, it is understood that the points marked 1 and 2 are resin and silica particle and chopped glass fiber, respectively (Sabău et al., 2012).

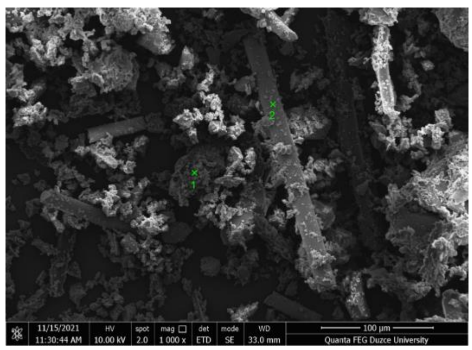
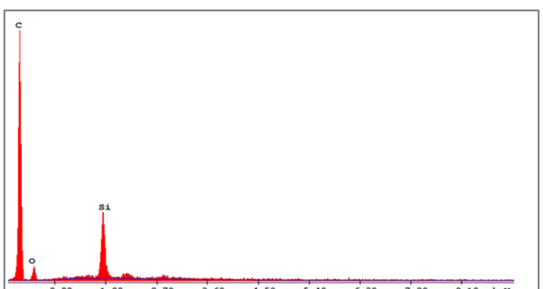


Figure 3. SEM photograph of the GFRP-WP showing resin and sand particles and cropped glass fibers.



Element	Wt %	At %	K-Ratio	Z	A	F
C K	81.77	88.29	0.3547	1.0064	0.4309	1.0001
O K	9.45	7.66	0.0141	0.9897	0.1511	1.0001
SiK	8.77	4.05	0.0771	0.9494	0.9258	1.0000
Total	100.00	100.00				

Figure 4. EDX analysis of the particles.

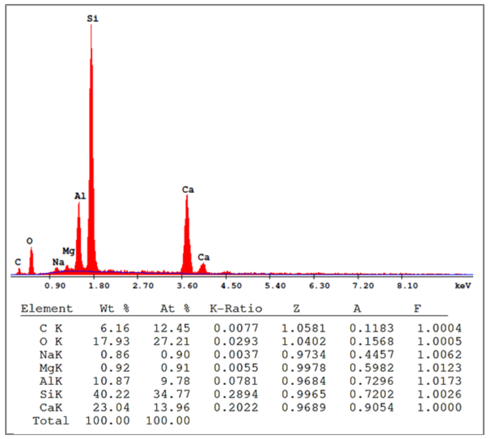


Figure 5. EDX analysis of the glass fiber.

GFRP-WP was dried in an oven, and some physical properties were determined by tests conducted in the laboratory. The polymer ratio in GFRP-WP was determined by heating it up to 600 ºC in the oven and burning the plastic material. It was determined that 40% of the waste material was made up of polymer, and 60% of it was made up of sand and fiberglass. The specific gravity of the material was found to be 2.34 gr/cm3. Granulometry of GFRP-WP found by sieve analysis is presented in Figure 6. All the GFRP-WP passes through one millimeter-span sieve. The gradation curve of the GFRP-WP is illustrated on Fuller's ideal gradation curves calculated by Equation (1) (Figure 3).

$$p_i = \left(\frac{D_i}{D_{max}}\right)^n \times 100 \qquad (1)$$

where i: sub-index of a particular sieve, Di: sieve size (mm), Dmax: the maximum aggregate size (mm), pi: percent finer than diameter Di, and n: the shape factor.

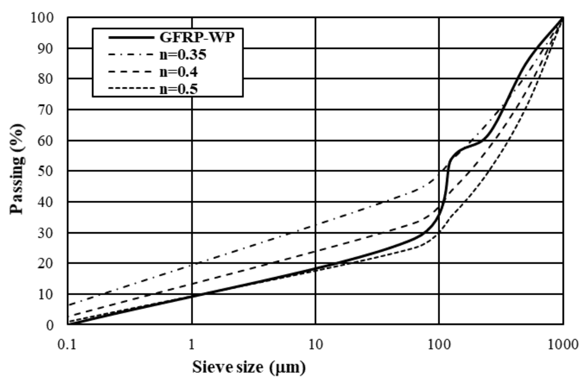


Figure 6. Sieve analysis of the GFRP-WP.

2.1.3. Mixture proportion

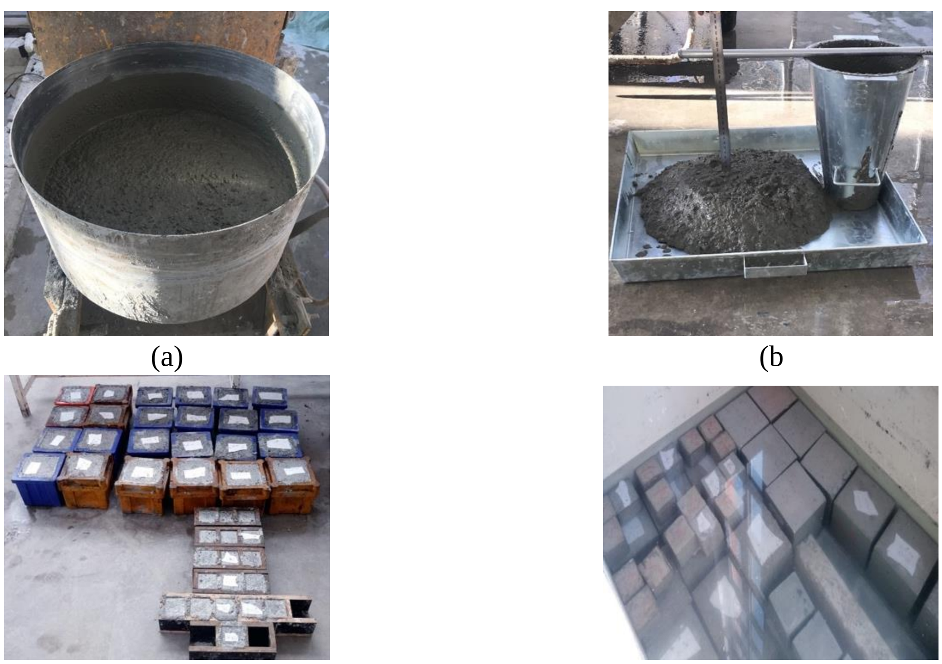
The mixture design of concrete specimens was prepared according to the Standard (TS 802, 2016), and presented in Table 1. Concrete specimens were prepared by adding different proportions by volume as a partial replacement to fine aggregate after GFRP-WP was completely dried in the oven. Concrete specimens produced with %0, 5%, 10%, 20%, 30%, and 40% GFRP-WP were represented by WP0, WP5, WP10, WP20, WP30,and WP40 respectively. Since the effect of GFRP-WP on workability would be examined water/cement ratio and the amount of water and cement were kept constant in the mixture design.

Table 1. Concrete mixture proportions (kg/m^3).

Specimens	GFRP-WP Ratio	Water	Cement 42.5	Air	Admixture	Coarse Aggregate (4-12 mm)	Coarse Aggregate (12-24 mm)	Fine Aggregate (0-4 mm)	WP (kg)
	%	(kg/m^3)	(kg/m^3)	(m^3)	(kg/m^3)	(kg/m^3)	(kg/m^3)	(kg/m^3)	(kg/m^3)
Control	0	204	384.91	0.014	2.92	442.07	614.28	712.59	0
WP5	5							681.71	30.88
WP10	10							650.83	61.76
WP20	20							589.07	123.52
WP30	30							527.32	185.27
WP40	40							465.56	247.03

2.1.4. Test specimen production

A total of 24 Concrete Specimens for compressive strength test, four from each group, and a total of 18 concrete capillarity and water absorption specimens, three from each specimen group were produced in the laboratory. The production steps of the specimens are illustrated in Figure 7. The specimens were produced in 150x150x150 mm standard cube molds, specimens for water absorption and capillarity tests were produced in 70x70x70 mm size cube molds. Concrete mixture materials were prepared by weighing them on a scale with a sensitivity of 0.1 gram and mixed in a laboratory mixer (Figure 7a). The workability of the prepared concrete specimens was checked with the slump test and placed in the molds (Figure 7b). The specimens kept in molds for 24 hours were removed from the mold and kept in the curing pool at 20 to 22 °C until they completed the 26-day curing process (one day in the mold and one day in the air before breaking, a totally of 28 days) (Figure 7c, 7d). Specimens that completed the compressive strength process were taken out of the curing pool and prepared for testing (Figure 7d).



(a) (b
(c) (d)

Figure 7. Production process of specimens: (a) mixing; (b) Slump control; (c) Specimens; and (d) curing.

2.2. *Test method*

2.2.1. Workability

The effect of GFRP-WP on workability and hardened concrete properties was investigated by keeping constant the concrete mixture parameters except for GFRP-WP and fine aggregate. According to the Standard (TS EN 12390-2, 2000), the workability of fresh concretes produced in six groups was determined by the Slump test. Workability tests of fresh concrete specimens were performed by frustum of a cone (Abrams funnel) with an upper diameter of 10 cm, a lower diameter of 20 cm, and a height of 30 cm.

2.2.2. Compressive test method

Compressive strength values of concrete specimens are determined in the concrete press testing device according to the Standard (TS EN 12390-3, 2019). The smooth surfaces of the specimens are placed between the cylinder heads of the concrete press and tested at a loading rate of 0.5 MPa/s. (Figure 8).

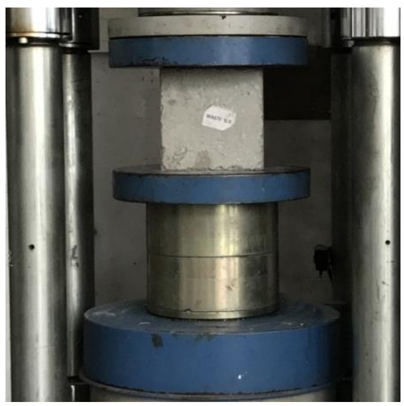


Figure 8. Compression test method.

2.2.3. Absorption test method

The water absorption rate determination tests related to concrete specimens are made according to the Standard (TS EN 12390-7, 2019). The specimens are dried in the oven at 105° C for 24 hours at the beginning of the experiment and weighed, and then the specimens are kept in water for 24 hours. The amount of water absorbed is determined by weighing the specimen taken out of the water. Equation (2) determines water absorption rates by weight.

$$WA_{24}=\frac{100(M2\text{-}M1)}{M1} \qquad (2)$$

Where WA_{24} : the percentage by weight of water absorption for 24 hours, M1: the oven-dry weight of the specimen, M2: the weight after being kept in water for 24 hours.

2.2.4. Capillarity test method

Capillary tests related to concrete specimens are carried out according to Standard (TS EN 480-5, 2008). In the experiment, firstly, the specimens are dried in an oven at 105° C for 24 hours and then kept until they reach room temperature. The specimens are prepared so that only one surface would allow water inflow (Figure 9.). The side surfaces of the specimens at a height to contact with water were coated with paraffin. The dry weights of the concrete specimens are measured first, and then the water absorbed weights at the 30th, 60th, and 120th minutes are measured, respectively. After calculating the amount of water absorbed by the concrete capillary in the specified periods, the capillarity coefficients in the relevant periods are calculated with Equation (3

$$kt=\left(\frac{Q}{A}\right)^2 \quad (3)$$

Where k: capillary coefficient (cm^2/sec), t: elapsed time (seconds), Q: amount of absorbed water (cm^3) and A: surface area in contact with water (cm^2).

Figure 9. Capillarity test.

3. Experimental results and analysis

The results of compressive strength, water absorption, and capillary water absorption tests of concrete specimens produced using GFRP-WP in the concrete mixtures in five different configurations by volume as a partial replacement to fine aggregate are presented and interpreted in this section. The experimental results are summarized in Table 2 with the standard deviation.

Table 2. Test results of concrete specimens at average.

Specimens	Compressive test results (MPA)	Standard deviation (SD)	Water absorption Results by weight (%)	Standard deviation (SD)	Capillarity results 10-6 cm^2/sec	Standard deviation (SD)
Control	42.36	0.442	3.1	0.100	0.6	0.4
WP5	45.15	2.359	3.2	0.153	0.8	0.5
WP10	43.66	1.342	3.4	0.115	1.8	0.6
WP20	33.78	1.438	4	0.100	3.5	2.1
WP30	29.31	1.375	6.3	0.265	3.7	1.9
WP40	27.77	1.230	6.9	0.231	5.5	2.4

3.1. *Workability results*

Since the workability of concrete is directly related to the mixing water, the effect of waste on workability was studied by keeping the W/C ratio constant in the concrete mixture. Before the fresh concrete specimens were placed in the mold, their workability was checked with the slump cone test and the results are presented in Figure 10. In the control concrete (WP0), the slump was measured as 200 ± 20 mm, and it was observed that the workability decreased as GFRP-WP ratio increased in the mixture. The aggregates in the concrete mixture had the feature of saturated dry surface, but, the need for mixing water increased since GFRP-WP is oven-dried. The values obtained in the workability test of GFRP-WP used as an oven drying showed that the optimum GFRP-WP mixture ratio was 20%, and GFRP-WP mixture rates of 30% and 40% had a negative effect on workability and other properties of concrete.

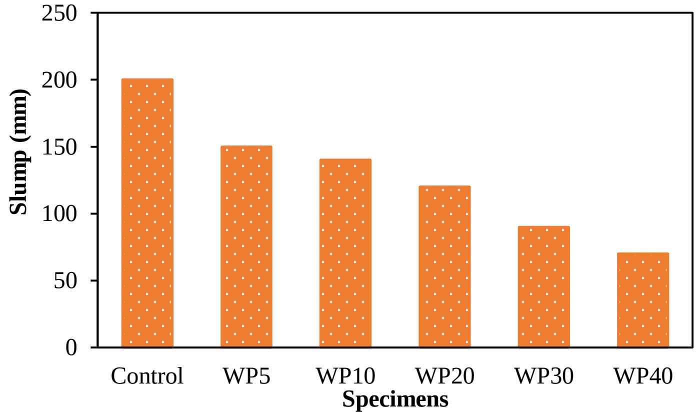


Figure 10. Slump test results of concrete specimens.

The workability test results show that a constant plasticizer additive content causes the collapse cone test to change from 200 mm in a GFRP-WP-free mix to 70 mm when 40% of the fine aggregate is replaced with GFRP-WP. This refers to the change of concrete fluidity from S4 to S2 consistency class according to Standard EN-206:2016. A study on self-compacting concretes states that at 15% and 20% replacement rate GRP significantly decreased the workability of the concrete, and workability is made suitable by adding 0.25% and 1% superplasticizer, respectively, according to the cement weight. (F. Tittarelli & Moriconi, 2010). The workability of concrete decreases due to the increase in the rate of powder material in the aggregate, and the demand for water increases (Alyamaç & Aydin, 2015; Damci, Temur, Bekdaş, & Sayin, 2015; Dobiszewska & Beycioğlu, 2020; Khodabakhshian et al., 2018). This increase in water demand is attributed to the relatively larger surface area and high fineness of GFRP-WP compared to fine aggregate.

3.2. *Water absorption results*

Water absorption tests were conducted on 18 concrete specimens in total, three from each concrete specimen group. The water absorption test results are presented in Figure 11. According to the control concrete, the increase in water absorption values by weight of WP5, WP10, WP20, WP30, and WP40 concrete specimens was determined as 3.2%, 9.7%, 29%, 103%, and 123%, respectively. As the rate of GFRP-WP increased, water absorption rate also increased. While the water absorption rate was at acceptable levels between 5% and 20% GFRP-WP, this value suddenly increased after 20%. As it can be understood from the slump test if the GFRP-WP exceeds 20 percent, the workability and placing of concrete become difficult. Due to these, the concrete turns into a more porous structure, and the water absorption of the concrete increases. In particular, when the workability of the concrete decreases, the result is that the concrete receives a more porous structure and thus the water absorption of the concrete increases.

Osakon et al. explained that GFRP-WP reduces the water absorption rate of concrete. However, while the water absorption of the control specimen is 3.1% in our study, it is 6% in theirs (Asokan et al., 2010). In addition, no explanatory information was given about the workability level of concrete and the placement method in the study. Therefore, it may be concluded that the water absorption level of the control concrete may alter the results. Mashaly et al. (2016) attributed the increase in the apparent porosity and water absorption of concrete mixtures containing marble powder to the increase in the high surface area and the ratio of marble powder (Mashaly, El-Kaliouby, Shalaby, El-Gohary, & Rashwan, 2016). For this reason, if the additional rate of waste material exceeds 20%, it may be recommended to use it in the concrete to be produced by applying the necessary and sufficient isolation procedures in places where water contact is concerned. In addition, it was concluded that if the additive rate exceeds 20%, the workability and fluidity must be controlled and regulated absolutely.

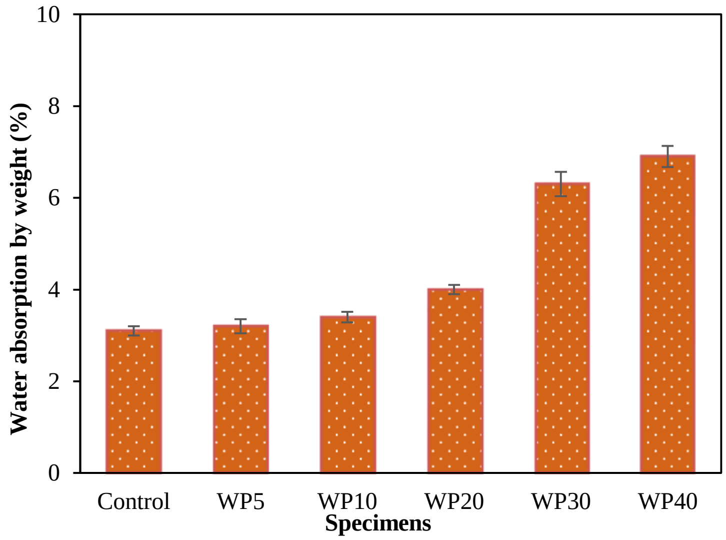


Figure 11. Water absorption rates of concrete specimens by weight.

3.3. *Capillarity results*

The results obtained from the capillary test by performing on a total of 18 concrete specimens, three from each concrete specimen group are presented in Figure 12. The capillary coefficient of the control concrete was 0.6 x10-6 cm^2/s. The Capillarity coefficient of WP5, WP10, WP20, WP30, and WP40 concrete specimens increased by 24%, 80%, 433%, 474%, and 745%, respectively. It is seen that there is a sudden increase in capillarity coefficients of WP20, WP30, and WP40 specimens compared to WP5 and WP10. This is because of increase in filler material in fine aggregate content, increase in concrete voids and increase in capillary structure due to decrease in workability. A similar situation was encountered in the water absorption test. Using GFRP-WP in concrete by at least 20% would be expected to reduce the capillarity coefficient (F. Tittarelli & Moriconi, 2010; Francesca Tittarelli, 2013; Francesca Tittarelli & Shah, 2013). However, when workability decreased, concrete specimens produced using GFRP-WP turned into a more permeable and porous structure. Topcu et al. showed that the use of low amounts of marble powder in self-compacting concrete reduces the capillarity coefficient of the concrete due to high workability and filling of the pores, but the capillarity coefficient decreases by increasing the specific surface area and porosity with the increase in the amount of marble powder(Topçu, Bilir, & Uygunoğlu, 2009). Türkmen and Kantarcı, who investigated the capillarity coefficients of self-compacting concrete, reported that the increase in the apparent porosity of the concrete produced with expanded perlite aggregate increased the capillarity coefficient (Türkmen & Kantarci, 2007).

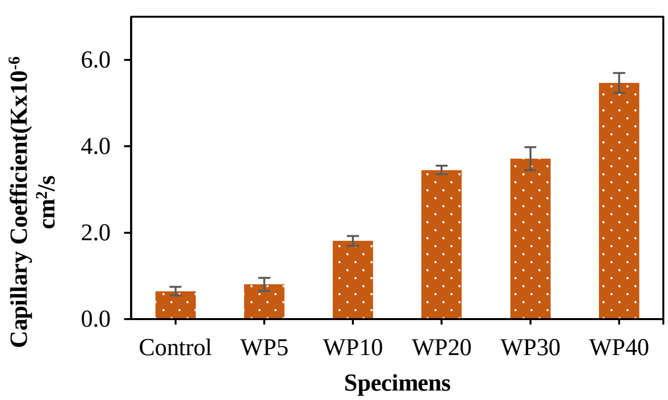


Figure 12. Capillarity test results chart of concrete specimens.

3.4. *Concrete compressive results*

Compressive strength tests were conducted on 24 concrete specimens, four from each concrete specimen group. The compressive strength test results are presented in Figure 13. The compressive strength of the control specimen was found to be 42.4 MPa on average. The compressive strength of the concrete specimens where 5% and 10% of GFRP-WP was added by replacement of fine aggregate increased by 6.6% and 3%, respectively. The reason is mostly based on the better dispersion of cement grains in the mixture with the dense matrix effect of GFRP-WP (Jain et al., 2020; Vijayalakshmi, Sekar, & Ganesh Prabhu, 2013) . GFRP-WP compounds are noted to have the potential to act as additives to improve the bonding and adhesion of concrete (Asokan et al., 2010, 2009). When GFRP-WP was added to the concrete mix as a partial replacement of 20%, 30% and 40% of the fine aggregate, compressive strengths of the concrete decreased by 20%, 31% and 34%, respectively. The decreased workability occurring with the increase of the GFRP-WP ratio of 20% and above made it difficult for the concrete to settle uniformly in the molds. The decrease of workability is attributed to increased specific surface area and specific density of GFRP-WP. The specific surface area and density of GFRP-WP increase in demand of paste volume and decrease the workability of the concrete resulting in high porosity (Vijayalakshmi et al., 2013). Therefore, especially increases in porosity between the cement gel structure and cement paste and aggregate interfaces decrease the compressive strength of the concrete. Asokan et al. used GFRP-WP in concrete as a partial replacement of fine aggregate without using a chemical plasticizer, and they expressed that GFRP-WP reduced the compressive strength of concrete (Asokan et al., 2009). In addition, they expressed that the compressive strength of concrete could be partially improved by using varying amounts of Superplasticizer according to GFRP-WP ratios (Asokan et al., 2010).

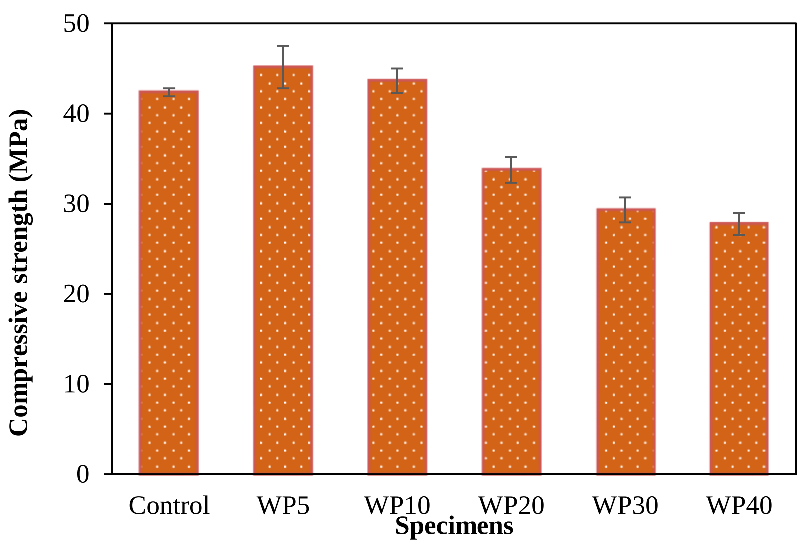


Figure 13. Compressive strength chart of concrete specimens.

Fracture patterns of concrete specimens under compressive load are presented in Figure 14. In the specimens fracture cracks initiate from the areas close to the cube corners and progress inclined towards the middle of the section. It has been observed that fracture cracks in the control concrete and WP5-20 concretes progress by breaking the cement paste and coarse aggregate. However, in WP30 and WP40 concrete specimens fracture cracks were observed to occur mostly at the cement paste and cement paste-aggregate interface, which can be attributed to the weakening of the cement paste with the increase in GFRP-WP ratio.

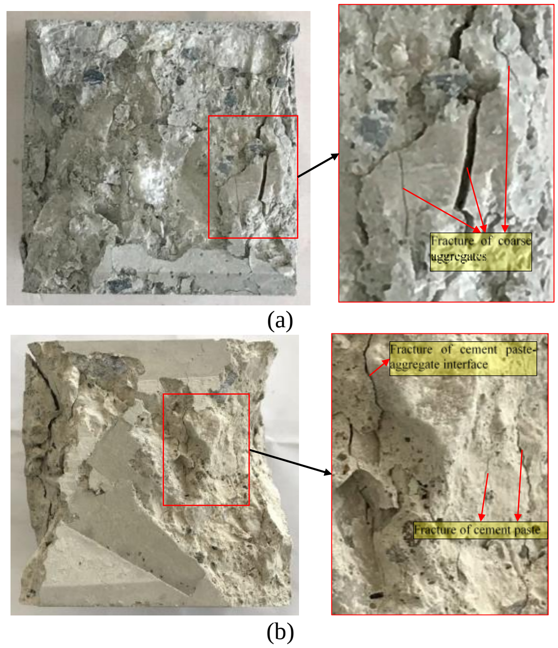


Figure 14. Failure pattern of concrete cube specimens under compressive load: (a) fracture of coarse aggregate; (b) fracture of cement paste-aggregate interface.

3.5. *Slump-water absorption and water absorption-resistance relationships*

The change between water absorption values by weight and the compressive strength corresponding to these values is illustrated in Figure 15. It was found that the water absorption value corresponding to the compressive strength of 45.2 MPa was 3.2%. If this absorption value increased by 1%, the compressive strength decreased by more than 10 MPA. According to these results, it can be repeated that the GFRP-WP ratio should not exceed 20% as a partial replacement for fine aggregates for concrete, the workability of which is not constant. When determining GFRP-WP ratios in concrete, workability should be checked and kept at the appropriate level.

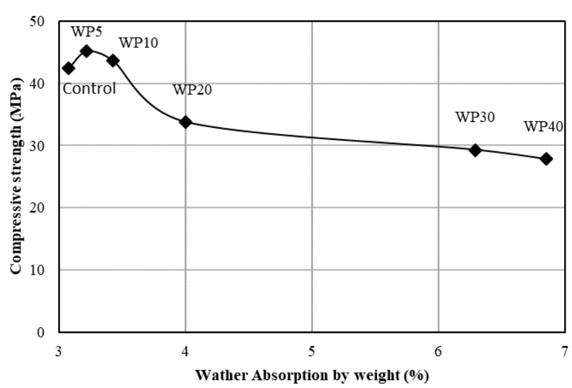


Figure 15. Relationship between water absorption by weight and compressive strength.

The relationship between workability and water absorption by weight was also investigated, assuming that the main variable depending on the GFRP-WP ratio in the concrete specimens is workability. While the slump value was between 20 and 12, the amount of water absorption was limited; when it was below 12 cm, the water absorption rate suddenly increased. It is clearly understood from Figure 16 that the porousness of the concrete is directly related to workability.

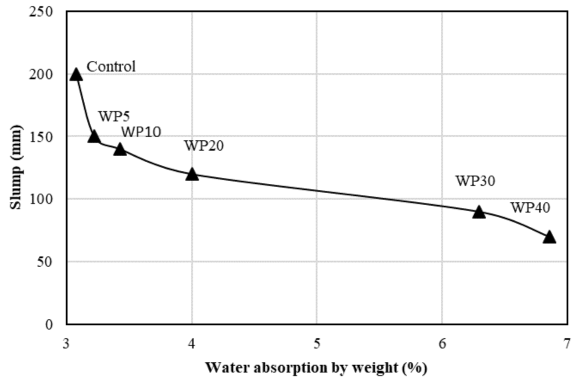


Figure 16. Relationship between water absorption by weight and slump.

4. Conclusions and comments

In this study, the use of GFRP-WP as filler content in concrete and its effects on concrete characteristics is investigated. The effect of workability in fresh form, compressive strength in hard form, weight and volume water absorption, and capillary properties is investigated in concretes produced by adding GFRP-WP as filler as a percentage of fine aggregate to the mixture in specific proportions. According to the results:

1. The addition of 5% and 10% GFRP-WP to concrete mixes as a partial replacement for fine aggregates increases the concrete compressive strength by 6.6% and 3% respectively. However, the addition of 20%, 30% and 40% GFRP-WP decreased the concrete compressive strength by 20%, 31% and 34%, respectively.
2. With the denser matrix effect of GRP-WP up to 15%, concrete compressive strength is increased with better dispersion of the cement particles in the mixture, but if this ratio is exceeded, concrete properties are impaired by the increase in the specific surface area of the fine aggregate and the decrease in workability.
3. As the GFRP-WP ratio in the concrete mixture increases, the workability decreases, and the water absorption rate increases. It was determined that the critical GFRP-WP ratio was 20%, considering the water absorption-workability relationship.
4. As a consequence of the decrease in the workability of concrete, concrete specimens produced with GFRP-WP turned into a more capillary and porous structure, significantly when the mixing ratio exceeds 10%.
5. As a result, using GFRP-WP up to 15% by volume as a partial replacement for fine aggregates will contribute positively to concrete strength and recycling. Considering the annual production capacity of concrete, recycling the waste in concrete will significantly eliminate the waste problem and provide more economical concrete production. In addition, GFRP-WP ratio can be increased by making a workability regulation in the concrete.

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Guven Gurbuz's contributions are the performance of water absorption experiments, literature research and the analysis of test results.

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