Environmental Science and Pollution Research (2021) 28:16843–16854
https://doi.org/10.1007/s11356-020-12195-9

RESEARCH ARTICLE

Possibilities of disposing silica fume and waste glass powder, which are environmental wastes, by using as a substitute for Portland cement

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Received: 7 June 2020 / Accepted: 21 December 2020 / Published online: 4 January 2021

Abstract

In this study, the possibilities of disposal of environmental waste, silica fume, and waste glass powder as substitutes in the mortar samples in Portland cement were investigated. For this purpose, Portland cement (CEM I), silica fume (SF), waste glass powder (WGP), CEN standard sand, and water were used in mortar production. Additive cements were obtained by using the SF, WGP, and SFWGP substitution methods in Portland cement at the rates of 10, 20, 30, and 40%. The flexural strength, compressive strength, radiation permeability (determination of linear absorption coefficient), high temperature, and alkali-silica reaction (ASR) effect on SF, WGP, and SFWGP were examined and compared with the control PC 42.5R samples. Mortar samples of 40 × 40 × 160 mm size were obtained with the grouts/mortars produced, and the samples were exposed to five temperature effects, namely, 20, 150, 300, 700, and 1000 ° C. Samples kept at 20 ° C are accepted as baseline. A total of 429 samples were studied, including the cooling process in the air (spontaneously in the laboratory, 20 ° C ± 2). After the samples achieved room temperature, flexural and compressive strength tests were carried out at 28 and 90 days. Test results demonstrate that SF, WGP, and SFWGP, which are environmental wastes, can be disposed both as a pozzolanic additive material both alone and together in cement mortars, can be utilized in buildings with high fire hazard, and the sample with the highest linear absorption coefficient is the sample obtained with SFWGP, and also, the expansion values that occur in SF and WGP are less than the control sample.

Keywords Alkali-silica reaction · High temperature · Portland cement · Radiation permeability · Silica fume · Waste glass powder

Introduction

In our age, the issue of utilizing waste materials in alternative fields of use has gained relevance globally in order to reduce the use of natural resources in building manufacturing processes. By using waste materials in different areas of the construction industry, it is aimed primarily to prevent the rapid consumption of natural resources, to recycle large amounts of waste material, thereby solving environmental problems caused by waste as well as reducing costs (Brooks and Cetin 2012; Akçaözoğlu and Akçaözoğlu 2016; Cetin 2013a, 2013b; Cetin 2015a, 2015b; Adiguzel et al. 2020; Gungor et al. 2020). Recycled plastic composes no hurtful emissions while it is being manufactured or while it is being used by the consumer. Plastic spills no toxic chemicals into the water or soil and recycling diminishes pollution. While recycling plastic, it helps to create eco-friendly products and prevents from putting tons of waste into our landfills. Since the use of plastics is increasing, the new method is considering a solution like recycling. One of methods is that some of the plastics get mixed in the other materials for recycling; the recycled plastic then becomes valuable. Whole plastic material can be used as a binder in the recycling of permeable pavements, which has also been an improvement (Brooks and Cetin 2012; Cetin 2020; Cetin 2013a, 2013b; Cetin 2015a, 2015b, 2015c, 2015d; Cetin 2016; Cetin 2019).

Environmental pollution, which is considered one of the most important issues that our world faces today,

Responsible Editor: Philippe Garrigues

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can occur naturally and artificially. Natural sources of pollution are wastes from all organisms, including humans. With natural recycling, nature can clean the pollution in a short time with its recycling mechanism. But artificial pollution particularly caused by industrial activities may remain in nature for a long time and cause negative effects on organisms and ecosystems (Brooks and Cetin 2012; Zeren Cetin et al. 2020; Zeren Cetin and Sevik 2020; Cetin 2013a, 2013b; Cetin 2015a, 2015b, 2015c, 2015d; Cetin 2016; Cetin 2019; Cetin et al. 2019; Cetin 2020; Cetin et al. 2020; Bayraktar et al. 2019a, 2019b).

With the industry that grows a little more each day, many waste materials emerge due to the production in this area. A significant portion of these waste materials released is stored and preserved, and as a result, environmental pollution increases even more (Bayraktar et al. 2019a). The construction industry consumes about 60% of the minerals obtained from natural resources (Vitale et al. 2017). On the other hand, clinker processes during the production of Portland cement, which is a fundamental component of concrete, contribute to approximately 5–8% of global CO_2 emissions (Alsubari et al. 2016; Maraghechi et al. 2017). These figures clearly demonstrate the need to increase the sustainability of the construction industry using waste minimization and recyclable engineering materials that consume less energy in production (Teixeira et al. 2016).

One of the most appropriate approaches to reduce the CO_2 footprint of concrete is to replace the raw materials used in clinker with natural resources, particularly substituting them with industrial by-products such as fly ash, blast furnace slag, and silica fume or recycled materials such as waste glass and plastic (Berndt 2009; Meyer 2009). The use of these wastes, which are harmful to the environment in the construction industry, reduces raw material and energy usage as well as the safe disposal of wastes. It is possible to implement "industrial symbiosis" with the use of waste materials in the construction industry. In this way, it does not only prevent the environmental issues originating from an industry but also provides economic returns (Demirel and Öz 2017).

Silica fume (SF): Silica fume, which emerges as a result of industrial production and is stored and preserved by means of special filters in the chimneys, is an industrial waste consisting of spherical particles with a very high amount of silica, and with generally glassy and smooth surface. Silica fume grains fill voids, reduce $Ca(OH)_2$ crystals, reduce porosity and permeability, and as a result increase the compressive strength of both concrete and cement (Bayraktar 2016).

Waste glass powder (WGP): Recycling of glass with high silica (SiO_2 > 70%) content, amorphous structure, and high surface area is an environmental issue (Öz 2017; Vijayakumar et al. 2013). Glass melting power structure and excessive recycling cost make recycling difficult. Glass powder showing pozzolanic properties is used as an alternative cement complementary material to give the concrete or mortar the desired strength and durability when the particle size is less than 0.075 mm or 0.038 mm. WGP forms calcium silica hydrate (CSH) gels that bind $Ca(OH)_2$, which is formed as a result of hydration of cement and water thanks to its pozzolanic activity, with high content of SiO_2 (Fathi et al. 2017; Kamali and Ghahremaninezhad 2016; Omran et al. 2017).

Since radioactivity harms human health, serious studies have been done in recent years (Bayraktar 2019; Cho et al. 2019; Hinck et al. 2017; Turhan et al. 2011; Dhami 2012). The radiation beam decreases in intensity when passed through a substance. This decrease depends on the thickness of the substance, the elements in it, and the concentration of the elements in the substance. Materials made of heavy elements are used to hold the X and γ rays. As an alternative to heavy elements such as lead with a high specific gravity and etc., it is important to identify other materials with high radiation trapping properties, hence using them in the industry (Bayraktar 2019). The fact that the basic materials used in construction are radiation-trapping is important both for creating a healthier living environment as well as being able to do this without requiring an extra process or burden (Sevinç 2011; Davraz et al. 2017).

Two types of alkali-aggregate reactions (AAR) are known today. These are the ASR and alkali-carbonate reaction (ACR). ASR is more common (Gökçe et al. 2010). ASR is the reaction of reactive silica found in concrete aggregates and hydroxyl ions present in the voids of concrete. For the formation of ASR, there should be reactive silica, high alkalinity pore solution, and sufficient moisture in the environment. Without any of these conditions, there will be no expansion due to ASR. This increase in volume caused by swelling in concrete causes cracking in the concrete, resulting in tensile stresses. The use of mineral additives improves mortar and concrete compressive strength, void structure, and permeability over time. Because of mineral additives, the total void decreases with the development of hydration. Mineral additives such as FA (fly ash) and SF (silica fume) are also known to reduce ASR expansions (Demir 2010; Bobrowsky and Marker 2018).

In this study, in addition to the usability of silica fume and waste glass powder from industrial waste materials in the construction industry, we attempted to determine how it changes the quality and radiation permeability of cement. In addition to investigating the physical and mechanical properties of these two waste materials under high temperature effect by substituting them in Portland cement at different rates together and separately, their ASR effect and radiation trapping properties were investigated as well.

Materials and method

Materials

Cement

In this study, PC 42.5R (CEM I) type of cement complying with BS EN 197-1 (2011) standard has been used. The chemical and physical properties of cement are given in Table 1 (BS EN 197-1, 2011).

Silica fume and waste glass powder

In the experimental study, silica fume (SF) and waste glass powder (WGP) were used as other additives. SF and WGP used in the experiments were ground to be finer than Portland cement. Chemical composition and physical properties of SF and WGP are given in Table 2.

Method

Cement manufacturing and cement experiments

It is produced in 40 × 40 × 160 mm dimensions by using the substitution method in SF, WGP, and SFWGP cement at the rates of 10, 20, 30, and 40% (Bayraktar 2016). The amount of water required in each group mixture was determined by the creep table test according to the creep diameter specified in ASTM C230, C109, and C1437 standards, and kept in a 95% relative humidity environment at room temperature of 20 °C ± 2 °C (Bayraktar et al. 2019b).

The chemical compositions of PC 42.5R, SF, and WGP used in the production of PC 42.5R, SF, WGP, and SFWGP samples were determined. Cement mortar test methods were made using triple steel mortar molds with dimensions of 40 × 40 × 160 mm (ASTM 2002). Flexural and compressive strength tests were carried out on 2 different days (28, 90) on three different samples (SF, WGP, and SFWGP) prepared with CEN standard sand. Samples produced in the form of prisms with the dimensions of 40 × 40 × 160 mm were removed from the molds 24 h after manufacturing, and kept in a laboratory environment with a 95% relative humidity at 20 ± 2 °C until the 28th and 90th days of experiment. Mixture ratios to be used in the experiments were determined depending on the mortar types, taking into consideration the creep ratio values, and mixing calculations were made. Sample of cement with binder was called PC 42.5R; samples with binder cement and silica fumes of 10%, 20%, 30%, and 40% were called SF10, SF20, SF30, and SF40; samples with binder cement and 10%, 20%, 30%, and 40% waste glass powder were called WGP10, WGP20, WGP30, and WGP40; and samples with binder cement and 10%, 20%, 30%, and 40% silica fume and waste glass powder were named as SFWGP10, SFWGP20, SFWGP30, and SFWGP40.

Table 1 Chemical and physical properties of PC 42.5R cement

Oxide	Value	Property	Value
SiO_2	20.36	Specific surface area, cm^2/g	3390
Al_2O_3	4.85	Volume expansion, mm	1.5
Fe_2O_3	3.05	Normal water content (%)	27.6
CaO	63.70	Initial setting time, min	185
MgO	1.57	Final setting time, min	230
SO_3	3.73	Density, g/cm^3	3.12
Na_2O	0.26	Fraction retained at 40 μm (%)	13.6
K_2O	0.78	Fraction retained at 90 μm (%)	0.8
Total	98.30		

High temperature applications

High temperature application was carried out in accordance with the principles specified in the BS EN 13501-1 standard (BS EN 13501-1 2007). Samples were kept in the drying oven (105 ± 5 ° C) before being exposed to high temperature (24 h) after 28 and 90 days curing periods. Samples that have been made dry in the oven are placed in the high temperature oven to determine the high temperature effect. During the heat treatment phase, they were kept under the high temperature effect of 150, 300, 700, and 1000 °C for 2 h in the high temperature oven with the heating rate of 6 °C/min (Bayraktar et al. 2019a). Reference specimens at 20 °C were not exposed to high temperature.

Cooling applications

Samples kept at 150, 300, 700, and 1000 °C for 2 h in high temperature application were cooled in the air (in the laboratory environment, 20 °C ± 2). After the samples were cooled, flexural and compressive strength tests were carried out. Depending on the temperature of the cooling rate of the samples that were left to cool, they were kept in a laboratory environment for about 30–180 min until the temperature reached 20 °C (Bayraktar 2012).

Compression and flexural strength test

Flexural and compressive strength values of the samples were determined 1 day after exposure to high temperatures, and 3

Table 2 Chemical composition and physical properties of SF and WGP

Oxide(%)	SF	WGP	Physical property	SF	WGP
SiO_2	93.52	72.89	Density, g/cm^3	2.25	2.60
Al_2O_3	0.30	1.04	Fraction retained at 40 µm (%)	-	7.8
Fe_2O_3	0.35	0.31	Fraction retained at 90 µm (%)	-	0.5
CaO	1.40	10.09	Specific surface area (Blaine) (m^2/kg)	20000	4830
MgO	0.75	2.60			
SO_3	0.21	0.73			
K_2O	-	0.20			
Na_2O	-	11.61			
LOI	-	-			
Total	96.53	99.47			

samples representing each group were allowed to cool (Bayraktar et al. 2019b; Ünal and Uygunoglu 2004).

Determination of alkali-silica reaction

- In order to reveal the harmful effects of active silica that can be found in aggregates, the accelerated mortar bar test has been applied according to ASTM C 1260

(ASTM C1260-07 2007). This method accelerates the reaction by aggravating the curing conditions, thereby allowing the reactivity of the aggregates to be determined within 16 days. A mixture of 2.25 times the mass (990 g) of aggregate and the water (206.8 g)/cement (440 g) ratio of 0.47 is prepared in the gradation specified in the ASTM C 1260 Standard. Mortar samples poured into molds of 25 × 25 × 285 mm dimensions were taken from the molds after 24 h, and their first length was measured. After the mold removal, the samples, whose length measurements were estimated, were kept in 80 °C water for 1 day, and their periodic measurements were estimated, keeping them inside a 1 M NaOH (900 ml pure water 40 g sodium hydroxide) solution at 80 °C for the following 14 days (Demir 2010).

Radiation trapping experiment

A total of 39 samples, 40 × 40 × 160 mm in size, each of which is made of 12 types of admixed mortar samples and PC42.5R samples without any additives, were prepared for experimental studies. With the HPGe detector prepared samples, their radiation permeability was determined by using the radioactive sources of ^{241}Am with 59.5 keV and ^{137}Cs with 661 keV, and their linear absorption coefficients were detected (Çalık and Şirin 2018).

Results

Elongation of the SF- and WGP-substituted mortar sticks under the effect of alkali-silica reaction

The equivalent alkali value of PC 42.5R cement used in the experiment is 1.09%. Different ratios of SF and WGP were used instead of cement. The experiments were repeated on at least three samples, the time-dependent expansion values obtained were determined for the 2-, 7-, and 14-day periods. As a result of the 2-day measurements, it was determined that the average highest elongation rate belonged to the PC 42.5R (non-substituted) samples without SF and WGP substitution with 0.050%, the average smallest elongation rate belonged to the SF40 mortar samples with 40% SF substitution as 0.018%, and it was found 0.045% for the WGP30 mortar bars, where 30% ACT substitution was made. As a result of the 7-day measurements, it was found that the average highest elongation rate was 0.130% for PC 42.5R (non-substituted) samples without SF and WGP substitution; the average smallest elongation rate was 0.021% for SF40 mortar rods with 40% SF substitution from SF samples, and the rate was 0.120% for the WGP30 mortar samples with 30% WGP substitution. As a result of the 14-day measurements, it was observed that the average highest elongation rate was 0.260% for PC 42.5R (non-substituted) samples without SF and WGP substitution, and the average lowest elongation rate was 0.035% for SF40 mortar rods with 40% SF substitution, and was 0.254% for WGP30 mortar samples with 30% WGP substitution from the WGP samples.

Expansion values occurring in SF and WGP under the effect of ASR reached the highest value of ASR expansion value in the displacement ratio of SF40 and WGP30, and the expansion values of the samples were measured lower than the PC 42.5R sample. This reduces the effect of ASR up to 40% displacement of silica fume and 30% of waste glass powder additive. As a result of the 14-day measurements, it is seen that the most optimum ratio of SF and WGP with 40% substitution rate, which provides lower expansion value than PC 42.5R, is SFWGP40 with 0.222%. Pozzolans act as diluents, because they are less reactive than Portland cement and release lower amounts of alkali. Mixtures containing pozzolanic additives have a higher effective water/cement ratio than mixtures containing only cement, which leads to further dilution of the alkali content. In addition, pozzolans reduce the pH of $Ca(OH)_2$ in cement paste and decrease its pH (Özkan 2007).

Flexural strength of SF and WGP additive mortars under high temperature

Twenty-eight and 90 days flexural test results of the SF, WGP, and SFWGP samples are given in Table 3. The results were evaluated in terms of the substitution ratio of SF and WGP into cement concerning mixing water, and the effects of the samples on the mechanical properties under high temperature were examined.

When Table 3 is examined, it was detected that the flexural strength values of SF10 and WGP40 samples in 28-day samples are higher than all temperatures of PC 42.5R sample, and the flexural strength values of the SF20 sample is greater than 20 (ref.), 150, and 300 °C of PC 42.5R sample. The flexural strength values of the SF40 sample are close compared to the temperature of 20 (ref.), 150, and 300 °C of the PC 42.5R sample. The flexural strength values of the samples WGP20, WGP30, and SFWGP10 are higher than the temperature of PC 42.5R sample at 150 and 300 °C degrees. It has also been determined that the flexural strength values of SF30, WGP10, SFWGP20, SFWGP30, and SFWGP40 samples are higher than the 300 °C temperature of the PC 42.5R sample.

It was detected that the flexural strength values of SF10 and WGP40 samples in 90-day samples are higher than all temperatures of the PC 42.5R sample, and the flexural strength values of the WGP20, WGP30, and SFWGP10 samples are higher than the 20 (ref.), 150, and 300 °C of the PC 42.5R sample. It was also found that the flexural strength values of the WGP10 sample are higher compared to the PC 42.5R sample at 150 and 300 °C, and flexural strength values of the SF20, SF30, SFWGP20, SFWGP30, and SFWGP40 samples are higher than the temperature of the PC 42.5R sample at 300 ° C.

It was determined that there was a difference between the 28th and 90th days according to the type of cement samples with additives, the increase in temperature values was in the opposite direction with the flexural strength value, and the flexural strength decreased as the temperature increased in the range of 300–1000 °C. When the flexural strengths of the produced samples at 28 and 90 days were compared, the highest and lowest strengths were seen in the samples at 300 °C and 1000 °C, respectively.

Compressive strength of SF and WGP additive mortars under high temperature

Compressive strength test results of the SF, WGP, and SFWGP samples at 28 and 90 days are given in Table 4.

Table 3 Flexural strength of mortar samples

Flexural strength (MPa)											
Conditions	Day	28					90				
	High-temperature treatment (°C)	20 (ref.)	150	300	700	1000	20 (ref.)	150	300	700	1000
Mortar type	PC 42.5R	8.6	8.8	7.9	5.1	2.8	9.5	9.8	9.4	6.9	3.4
	SF10	9.5	10.1	10.8	7.1	3.7	10.2	10.3	10.9	7.7	3.9
	SF20	8.7	8.9	9.4	3.8	0	9.1	9.4	9.8	4.1	0
	SF30	8.6	8.7	9.3	3.1	0	8.9	9.2	9.6	3.3	0
	SF40	7.9	8.2	6.7	1.8	0	8.3	8.4	7.6	2.5	0
	WGP10	8.1	8.8	9.6	4.1	1.5	9.4	10.1	10.8	5.1	2.1
	WGP20	8.3	8.9	9.7	4.5	1.7	9.6	10.3	10.9	5.4	2.5
	WGP30	8.4	9.1	9.9	5.1	2.1	9.8	10.6	11.2	6.9	3.2
	WGP40	8.9	9.7	10.5	7.2	3.9	10.4	11.3	11.9	8.9	5.6
	SFWGP10	8.5	9.2	9.9	4.9	2.6	9.6	9.9	10.6	6.1	3.3
	SFWGP20	8.3	8.6	9.3	3.9	0	9.1	9.6	10.1	5.3	0
	SFWGP30	8.2	8.5	9.2	3.7	0	8.9	9.5	9.9	5.1	0
	SFWGP40	8.1	8.4	8.5	3.1	0	8.7	9.3	9.7	4.7	0

Table 4 Compressive strength of mortar samples

Compressive strength (MPa)											
Conditions	Day	28					90				
	High temp. app. (°C)	20 (ref.)	150	300	700	1000	20 (ref.)	150	300	700	1000
Mortar type	PC 42.5R	46.8	48.8	46.2	29.2	12.9	53.2	54.9	53.5	32.7	13.8
	SF10	53.4	56.4	60.8	39.9	15.2	57	57.7	61.4	42.9	16.5
	SF20	52.4	53.8	56.5	22.6	5.8	54.2	56.5	58.3	24.4	6.4
	SF30	50.9	51.9	55.9	18.4	4.3	52.5	54.6	56.8	19.2	2.4
	SF40	45.2	46.9	38.7	10.5	0	49	49.7	45.1	8.6	0
	WGP10	48.4	51.7	55.3	28.1	12.6	53.9	57.5	61.5	31.5	13.6
	WGP20	43.8	47.6	51.7	28.7	12.8	49.3	53.5	58.1	32.5	13.7
	WGP30	39.1	41.9	44.8	29.4	14.4	44.4	47.5	50.8	33.5	15.8
	WGP40	34.3	36.7	39.3	29.7	17.5	38.9	41.6	44.5	33.7	19.2
	SFWGP10	49.7	52.6	56.9	33.8	13.8	54.3	59.7	63.7	39.2	15.7
	SFWGP20	47.1	49.7	53.1	26.7	11.3	52.4	55.8	58.9	30.2	13.6
	SFWGP30	43.1	45.8	49.5	25.4	10.9	48.7	51.5	54.6	28.5	12.1
	SFWGP40	39.2	41.3	38.9	23.6	8.1	46.1	48.3	44.8	24.2	10.9

The results were evaluated in terms of the substitution ratio of SF and WGP into cement concerning mixing water, and the effects of the samples on the mechanical properties under high temperature were examined.

When Table 4 is examined, it was determined that the compressive strength values of SF10 and SFWGP10 samples for 28-day samples are higher than all temperatures of PC 42.5R sample, the compressive strength values of the WGP10, SF20, SFWGP20, and SF30 samples are higher than the PC 42.5R sample at 20 (ref.), 150, and 300 °C degrees. Also, the compressive strength values of the WGP30 and WGP40 samples were higher than the PC 42.5R sample at 700 and 1000 °C, and the compressive strength values of WGP20 and SFWGP30 samples were higher than the PC 42.5R sample at 300 °C.

It was found that compressive strength values of SF10 and SFWGP10 samples for 90 days are higher than all temperatures of PC 42.5R sample. The compressive strength values of WGP10 and SF20 samples are higher than the PC 42.5R sample at 20 (ref.), 150, and 300 °C, the compressive strength values of the SFWGP20 sample are greater than PC 42.5R sample at 150 and 300 °C, the compressive strength values of the WGP30 and WGP40 samples were found to be greater than PC 42.5R sample at 700 and 1000 °C, and the compressive strength values of the WGP20, SF30, and SFWGP30 samples were higher than the PC 42.5R sample at 300 °C.

When the compressive strengths of the produced mortar samples at 28 and 90 days were compared with each other, the highest and lowest strengths were seen in mortar samples at 300 °C and 1000 °C, respectively.

The radiation trapping experiment of the SF and WGP-additive mortars

Linear absorption coefficients of the samples with SF, WGP, and SFWGP additives and non-additive PC 42.5R sample were obtained at 59.5 keV and 661 keV energy levels and given in Table 5.

The linear absorption coefficient indicates the radiation trapping value of a material. The greater the μ value, the higher the radiation trapping feature is. It can be seen from Table 5 that the maximum radiation of the beams with 59.5 keV energy is kept by the PC 42.5R sample. The most irradiated sample was WGP40. In this energy, in order to use

Table 5 Determination of linear absorption coefficients (μ: cm^{-1})

Energy	Sample name	μ(cm^{-1})	Energy	Sample name	μ(cm^{-1})
59.5 keV	PC 42.5R	0.584	661 keV	PC 42.5R	0.166
	SF10	0.375		SF10	0.161
	SF20	0.367		SF20	0.141
	SF30	0.355		SF30	0.125
	SF40	0.339		SF40	0.110
	WGP10	0.352		WGP10	0.167
	WGP20	0.332		WGP20	0.151
	WGP30	0.314		WGP30	0.139
	WGP40	0.295		WGP40	0.125
	SFWGP10	0.363		SFWGP10	0.168
	SFWGP20	0.351		SFWGP20	0.144
	SFWGP30	0.336		SFWGP30	0.135
	SFWGP40	0.319		SFWGP40	0.119

PC 42.5R sample in industry, its thickness must be increased. It is understood that the highest radiation of the 661 keV-energy rays is held by the SFWGP10 sample, but that energy trapping is not sufficient. The most irradiated sample was SF40. It is clearly seen that the values of linear absorption coefficient decrease with increasing energy. In addition, it is observed that there is a reduction in linear absorption coefficient with increasing additive rates at lower energy. The reason for this is that the atomic number of calcium (Ca) value, which corresponds to increasing percent ratios, is higher than other elements. Thus, the decrease in calcium caused lower values of linear absorption coefficient (Yılmaz 2011).

Discussion

Today, the most commonly used binding agent in the construction industry is Portland cement. Portland cement is not only the product of an industry that is produced using intense energy; it is also responsible for CO_2 emissions called greenhouse gases. Approximately 7% of the total CO_2 emissions worldwide are due to cement production (Turner and Collins 2013). Emissions from the facility during cement production are CO_2, NOx, SO_2, and toxic substances. In particular, dust emissions from cement kiln chimneys are important environmental issues. Therefore, cement production contributes significantly to global warming and climate change. For this reason, it is important to investigate the materials that can be an alternative to cement or that can be used instead of cement at a certain rate, as this will reduce the environmental problems and energy need arising from this industry. It is possible to contribute to the country's economy by saving energy, producing cheaper and higher quality materials, and recycling waste materials in case of utilization of waste in the construction industry globally. However, more research is needed to examine the effects of construction materials obtained from waste materials on durability, economy, and environment (Demirel and Öz 2017).

In this study, it was determined as a result of the experiments carried out on the samples that the compressive strength of the SF10 sample and binary mixture of SFWGP10 have higher values than the strength of the PC 42.5R sample in all temperatures at 28th and 90th days for the produced doped samples, and the values of the samples of WGP10 and WGP20 as well as the binary mixtures of SFWGP20 and SFWGP30 are close to the strength of the PC 42.5R. As is well known, materials with pozzolanic properties form calcium silica hydrate (CSH) gels that add additional strength to the mortar by binding $Ca(OH)_2$, which is formed as a result of hydration of water with cement (Omran et al. 2017; Shayan and Xu 2006; Schwarz et al. 2008; Topçu and Canbaz 2004). In addition to this positive effect, the microstructure in the interface transition region has led to a denser and more compact mortar due to the finer particle structure than SF and WGP cement. Thus, the compressive and flexural strength of the mortar has improved (Du and Tan 2017).

According to the test results, an improving effect of SF and WGP on compressive and flexural strength was observed. The reason for this situation can be explained by the content of SiO_2. The SiO_2 contents of WGP and SF used in this study are 72.89% and 93.52%, respectively. This situation can be explained as follows: The replacement of silica fume and waste glass powder, which has a high level of silica content, with cement has reduced the Ca/Si ratio, and has been connected to the more alkaline (basic) CSH phase, and the improvement in strength values has been higher (Du and Tan 2017; Lothenbach et al. 2001). It was obtained from the experimental results that high strength concretes can be produced by using WGP and SF together especially in higher ages. Looking at the microstructure examinations, it is seen that the internal structure of the admixed cements has turned into a more filled structure with CSH gels, which result from the pozzolanic reaction. $Ca(OH)_2$, which forms as a result of cement hydration, starts to react with pozzolans. As a result, an increase in the amount of C–S–H gels that give strength to concrete occurs. The increase in compressive strength with the amount of pozzolan on 28th and 90th days can be explained in this way.

As a result of the study, it was observed that aggregate distribution, crack development, and void structure could not be differentiated well up to 300 °C in the structure of the sections taken from high temperature applied samples, but at higher temperatures, the cracks between the aggregate grains of the binding agent increased gradually. The harmful effect of high temperatures was more pronounced and severe on flexural strength compared compressive strength. It was determined that flexural and compressive strengths decreased at all temperatures after 300 °C on the 28th and 90th days. This can be attributed to the destruction caused by the increased vapor pressure due to the high internal pressure under the influence of high temperature. In addition, it can be shown that strength increases up to 300 °C, and SF and WGP mineral additives decrease the amount of void in the mortar samples. The amount of $Ca(OH)_2$ decreases in the system due to the pozzolanic reaction between the reactive silica (SiO_2) in mineral additives and $Ca(OH)_2$ in the cement (Demirel and Kelestemur 2011). It may be shown that mixtures containing certain mineral additives, which are substituted in cement, contain less calcium hydroxide compared to pure PC pastes, which causes an increase up to 300 °C. The decrease in relative compressive strength occurring at temperatures exceeding 300 °C can be attributed to the decrease in the compressive strength of the structural water loss in the aluminous and iron oxide components in the cement. In addition, vaporization of the bound water that does not evaporate under normal conditions at temperatures exceeding 300 °C increases the level of destruction. Thus, the compressive strength of the mortar samples decreases. As is well known, one of the components found in cement paste is $Ca(OH)_2$. The conversion of $Ca(OH)_2$ to quicklime (CaO) is over 400 °C. At temperatures above 400 °C, it is known that CS–Hs begin to be destroyed, the strength decreases rapidly, and around 900 °C CSH structure is known to be completely dispersed (Bayraktar 2016). In particular, low values were obtained for some experimental results belonging to samples at temperatures of 700 and 1000 °C, especially for 90-day samples.

Comparing the reference cement with cements doped with SF and WGP, it is concluded that the most appropriate additive rate in terms of strength, physical properties, and usability is 20%. The sample with the highest linear absorption coefficient at 661 keV is the sample obtained with SFWGP10. In other words, it is the sample with the least radioactive permeability. The SF doping also reduced the expansion values at all displacement rates. The WGP additive decreased ASR expansion value at 30% displacement, while higher value was obtained at 40% displacement compared to the reference. In the study, it was seen that using SF and WGP together with 40% substitution rate had a great effect on ASR expansions. In addition to this, it shows that the optimum substitution amount for ASR should be determined by considering only the elongation. According to these results, the optimum rate for ASR is 40% for SF, 30% for WGP, and 40% for SFWGP, which is the binary mixture. In addition, we can say that it provides trapping of alkaline products with the reduction of alkali in SF and WGP cement. As a result, the ratio of SF and WGP that substitutes cement significantly affects the ASR expansion of reactive aggregates.

Studies on the use of different substitutes by mixing them in cement are particularly important both in terms of disposal of waste materials and cost reduction. Therefore, many studies have been done on this subject. Matos and Sousa-Coutinho (2012) replaced waste glass pieces with cement at the rate of 10, 20, and 40%. With the observation made by the electron microscope, they determined that the glass particles solidly encapsulated in the dense gel layer are the factors that increase the strength of the concrete, and as a result, they concluded that the waste glass powder has a positive effect in terms of sustainability in construction technology. Lu et al. (2017) determined that the waste glass powder shortened the setting time of the mortars with a lower hydration temperature, and the replacement of the glass powder with 20% cement increases the strength of the sample. Bozkurt and Karaca (2019) determined that waste powders used up to 20% instead of cement exhibit similar strength and durability characteristics with cement.

Ez-Zaki et al. (2018) used glass powder and mussel shell powder as waste material. Glass powder and mussel shell powder reduced the thermal permeability of the material and found that it can be used in insulation works. Younes et al. (2018) investigated the use of rice husk ash and waste glass pieces in the production of cement mortar composites. The results showed that both the waste glass and rice husk ash improved compressive strength values and increased hydration time in all mortar samples, and decreased physical properties such as porosity and water absorption capacity.

Karakulak (2019) stated that the use of cable waste 10% alone and 10–20% fly ash in the mortar mix provide good results, while the use of fly ash 10 and 20% alone gives good results. Korkmaz (2020) concluded that travertine waste and perlite can be utilized by adding them up to 20% at most into cement. Doğan (2018) found that 5% marble powder (MT) substitution provides optimum flexural and compressive strength in the substitution of standard sand with marble powder. Similarly, another conclusion was that fly ash (UK) substitution at 20% shows optimum mechanical properties in mortars. He also determined that the use of 15% marble powder and 15% fly ash improve the mechanical properties of mortars. Khodabakhshian et al. (2018) have determined that the durability and strength of the waste marble powder containing concrete tends to decrease for substitution rates above 10%, but satisfactory results are achieved below this level.

Orhan and Şahin (2016) determined that the compressive strength of ground concrete with additive waste glass powder at 600 and 900 °C increased compared to concrete in the control group, and the optimum use of ground glass powder was 10%. Lu and Poon (2018) also determined that the increase in the amount of waste silica glass fragment increases the process ability, and in the same vein, the mechanical properties and resistance to high temperature increase as well.

According to the results of radiation permeability, the absorption coefficient of PP 3 (50% Polypropylene (PP)), 30% waste mud (WM), and 20% egg shell (ES) sample is higher than the other composite samples produced by Uysal (2019). They stated that the use of egg shells reduced radioactive permeability, and therefore can be used in structures that are exposed to radiation effect. Esen et al. (2017) found that thanks to boron additives, a 30% higher neutron absorption coefficient value was obtained than Portland cement. New trends in environmental regulations are particularly directed towards the industrial use of waste products such as blast furnace slag, fly ash, and waste glass powder, in the production of mortar and concrete instead of cement or aggregate (Sarıdemir 2016; Chouragade and Abhyankar 2020; Siddique and Mehta 2020). In addition to Lo et al. 2020 currently worked with waste management for previous cement in Taiwan to effect of various types of pretreated ashes which are the recycling of ashes as a previous cement discussed in the current work are the result of evaluation the suitability of these various types of pretreated ashes for certain applications (Lo et al. 2020). Luo et al. 2020, studied with the mixture of fly ash slag which creates hydration products for solidifying heavy metals and ensuring the safe treatment and application of reconstructed slag (Luo et al. 2020). Environmental pollution can be prevented by utilizing waste as raw materials and can be provided by converting waste to construction material for the benefit of the economy (Merkit et al. 2018; Yılmaz 2014; Akyıldız et al. 2017; Kaplan et al. 2020a; Subaşı et al. 2017). Using these wastes, it is necessary to obtain new raw materials utilized alone or mixed with other materials in the production of new materials that comply with the standards and do not harm the environment (Bilgin 2010). CO2 emission can be minimized with the use of industrial wastes such as fly ash, blast furnace slag, and silica fume in cement-based systems (such as plaster, mortar, concrete), and the need for energy is reduced with natural resources (Tangüler et al. 2015; Kumar et al. 2020). Bheel et al. 2020, worked with coconut which is giving the results of improving of the sustainability of concrete (Bheel et al. 2020). Kaplan et al. 2020b, worked with current recycled aggregates with low strength produced low-strength concrete.

Conclusions

As a result of the study, it has been determined that environmental wastes silica fume and waste glass powder that harm the environment can be used in cement production, both separately and together, with different rates. Since these materials are waste materials, their use in mortar is important in terms of preventing environmental pollution, thereby reducing the costs of the produced samples. What is important at this point is to know how the quality of concrete changes depending on the proportions of the materials used. According to the results obtained in this study, the compressive strength values of SF10 from the SF samples on day 28 were higher compared to all temperatures of PC 42.5R sample, and the compressive strength values of SF20 and SF30 samples at all temperatures were closer to the strength of PC 42.5R sample. It has also been determined that the SFWGP10 samples with binary mixtures and WGP have higher strength than the PC 42.5R, and the WPG-doped SFWPG10 and SFWPG20 samples with binary mixtures have higher strength values that the SF40-doped cement.

It was found that the compressive strength values of the SFWGP10 on day 90 are higher than all temperatures of PC 42.5R sample; compressive strength of the SF20 sample at all temperatures is close to the strength of PC 42.5R sample, the SFWGP10 binary mixture samples with WGP have higher strength than the PC 42.5R sample, the SFWPG10 binary mixture sample doped with WPG has higher strength value than cement with SF20, SF30, and SF40 additives, and the SFWGP20 sample has higher strength value than SF40-doped cement. Use of mineral additives in binary mixtures eliminated the deficiencies that occurred by using mineral additives alone. In other words, mineral additives complementing each other in the SFWGP mixture and compressive strengths having closer or higher values than the reference specimen demonstrate that it provides a more homogeneous structure, reducing the number of voids and ettringite. Another important issue is that its contribution to the environment and economy in binary uses can provide significant benefits. In the cements to be produced, it will be useful to determine the mixing ratios by considering these results.

Therefore, it can be said that the most suitable mixture for use in terms of fire resistance is SF10, but when evaluated in terms of multidimensional factors (financially and environmentally) instead of solely looking in terms of fire, it can be said that the most suitable mixtures are SFWGP10 and SFWGP20 with WPG mixtures. Considering the results of this study on the cements to be produced, we recommend selecting the rates of additives that do not compromise significantly in cases of high temperature in concrete design. For example, in 28- and 90-day compressive strengths, the SF and WGP additives provide values closer to or higher than PC 42.5R compressive strength, and especially all binary mixtures providing higher values than the PC 42.5R sample shows that using these two different industrial wastes in cement can be helpful in producing affordable and environmentally-friendly cement with less harm to the environment.

High temperature is an important factor in sustainability. It causes significant losses in concrete design and mechanics. Events such as fire, explosion, and flaming that may cause high temperatures should always be considered. It has been determined that cement mortars will suffer less from the high temperature effect by using silica fume and waste glass powder, substituting it with cement. Studies can also be carried out in higher temperature ranges. Thus, it can minimize possible accidents in buildings that may be exposed to high temperatures. Nowadays, durability is also an important parameter in addition to strength for the production of sustainable buildings. In the study, it will also be useful to examine the admixed cements that are evaluated in terms of physical and mechanical compatibility with durability. The positive effects of the admixed cements on the concrete durability will ensure that the structures will serve for years without any problems.

It was obtained from the experimental results that high strength concrete can be produced by using WGP and SF together. Also, beside the pozzolan feature of WGP and SF, it is thought that the amount of fine aggregate can be reduced thanks to the micro-filler feature, and also the pozzolan feature can be increased by increasing the fineness. The SFWGP40-substituted samples of binary mixtures provide the lowest elongation, while the SFWPG-substituted samples provide the highest compressive and flexural strength under high temperature. This showed that the space-filling effect and the pozzolanic activity of the SF and WGP substitution are more effective in ASR. Reducing the amount of cement by 40% and substituting it with the materials found as waste in nature will create cement economy, providing the outcome that reduced strength in the series can be neglected as the waste materials will be eliminated by reusing them in the industry at a high rate.

After the nuclear power plant accidents, a large amount of fission products, ^{137}Cs, were released into the atmosphere. Therefore, it is exposed to continuous radiation from the atmosphere. Some types of concrete are used as construction materials. Radiation absorption coefficients need to be determined for people living in these structures. The absorption coefficients can be calculated by expanding the energy ranges of this study, which is carried out in certain energy ranges. Thus, a larger mass absorption table can be obtained. In addition, absorption parameters can be compared with these results by pulverizing concrete samples and making the same measurements. Absorption parameters of pure additives such as cement, silica fume, fly ash, blast furnace slag, and waste glass powder can be determined. Thus, these results can be compared with mixed concrete samples. In addition, by measuring the radioactivity of these materials, a concrete sample that gives the least radiation to the environment, thereby absorbing the radiation from the outside, can be determined. The SF40 was the most transmitting sample from 661 keV energetic rays. It shows that the SFWGP10 sample holds the most radiation, but energy trapping is not sufficient. Still, it can easily be used as a radiation trapping material with this thickness in places that operate with low energy rays.

Environmental factors should be considered in a sustainable concrete design. It is known that the destruction of nature and environmental pollution is prevented to a certain extent by reducing carbon dioxide (CO_2) and greenhouse gases emitted in cement production. Today, the technical and economic potential of this production should be reconsidered with a sustainable architectural perspective; it should be provided to the country's economy with an environmentally sensitive perspective, and presented to the benefit of the construction industry. Thus, it can provide significant benefits in terms of environment, economy, and most importantly, human life.

Availability of data and materials Not applicable.

Authors' contributions Oguzhan Yavuz Bayraktar: design, resources, writing; materials, data collection and/or processing; materials, literature search, analysis and/or interpretation.

Compliance with ethical standards

Competing interest The authors declare that they have no competing interests.

Ethics Approval Not applicable.

Consent to participate Not applicable.

Consent to publish Not applicable.

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