Journal of Cement Based Composites 1 (2023) 5773
Cement Based Composites
journal home: www.acapublishing.com/journals/5/cebacom

Research Article

An Investigation of Cement Mortars Containing Glass Powder as A Partial Cement Replacement

Göksu Pılsım*,[1], Demet Yavuz[2], Şemsi Yazıcı[3]
[1,3]Faculty of Engineering, Civil Engineering Department, Ege University, Erzene Avenue, 35040, Izmir, Turkey
[2]Faculty of Engineering, Civil Engineering Department, Van Yüzüncü Yıl University, Bardakçı Avenue, 65080, Van, Turkey

Keywords

Glass powder,
Cement mortar,
Waste,
Mechanical properties,
Cementitious material.

Abstract

Lately, because of the pollution caused by cement production waste materials that can be used instead of cement aroused interest by researchers. Glass is one of these waste materials. Glasses due to their nonbiodegradable properties, cause serious environmental risks and recycling this waste material would minimize these environmental concerns. Therefore, finely granulated glass powders, due to their high silicious content are being used as pozzolanic admixture. In this study, glass powders are replaced with cement (by weight) at 0%, 5%, 10% and 15%. And mechanical and durability performances are investigated. Compressive and flexural strength, flow test, abrasion resistance, sulfate resistance and capillary water absorption test were conducted. Results indicated that an increase in glass powder dosage in cement mortars leads to decrease in mechanical properties.

1. Introduction

Glass is a largely used material in our daily life. From soda bottles to jars, windows to industrial materials glasses find themselves a wide area of utilization. Because of this largely usage FEVE reported that in 2021 23.4 million tons of glasses were produced for global markets [1]. It should be also noted that in 2018, only 21% of the glasses that were manufactured were recycled [2]. Therefore, the large part of the manufactured glasses is not recycled. These glass ruins remain in residual areas or in landfills and, they pose a threat for human beings or animals. For the reasons explained above, glass is introduced to the literature as partial cement replacement agent [3-5]. It is reported that particle size of glass powder is the main factor for usability of lass in cement-based composites. Because in coarse fraction, glass can cause ASR (alkali-silica reaction) in the concrete mixes [6]. It is possible to minimize ASR with pozzolanic materials [7-8] or with adding steel fiber [9]. Finely granulated glass powders do not cause ASR in concrete mixtures therefore, most of the researchers focused on this area.

Because of their high silica content, glass powders act like a pozzolan and enhance the concrete mechanical properties and durability performance. [10] reported that glass powders finer than 40 µm has higher $Ca(OH)_2$ consumption and fiber glass powders have the highest pozzolanic activity. Other researchers such as [11-13] also reported that fineness of the glass powder has a significant effect on pozzolanic activity. While [12] reported that glass powder grain size smaller than 300 µm had a positive effect on pozzolanic activity, [11] reported that grain size between 45 µm and 75 µm increased pozzolanic reaction. [14] reported that particle sizes above 100 µm caused cracking within mixture due to ASR.

Recommended glass powder ratio is between 10-40%. [13] showed that minimum usage of glass powder at 10% replacement of cement is acceptable for pozzolanic admixture. [15] is also showed that 20% usage of glass powder caused higher degree of hydration.

Kamali and Ghahremaninezhad [16] investigated the effect of glass powders (two different types) in cement mortars and hydration, pozzolanic reactivity and microstructure of the cement paste is evaluated. They reported that glass powders (both of them) improved the early hydration. And glass powders can act like a pozzolanic material. Elaqra and Rustom [17] studied the glass powders as partial cement replacement (0, 10, 20, 25, 30%) and reported that usage of glass powder at higher dosages leads to decreased linear and volume expansion. This is the result of reduced ASR. Nahi et al. [18] used green recycled glass in cement mortars and replaced cement with glass powders by weight at 0, 10, 25, 35, and 60%. Increasing replacement ratio causes to lower compressive strength especially at the ratio of 60%. They also indicated that increased glass powder rate leads to bigger pores within mortar structure.

In this study, using waste materials as a cement replacement is investigated. Production of cement leads air pollution and therefore, researchers are exploring other options to limit usage of cement in cementitious material. Waste materials are one of the options that is being considered. Hence, glass powders obtained from waste glasses are used as supplementary cement material. Mechanical properties of cement mortars are investigated. Replacement ratio of the glass powders are as follows: 0-5-10 and 15% (by weight). Compressive and flexural strength, density, flow, and abrasion tests were caried out.

2. Materials and methods

2.1. Materials

In this study, CEM I 42.5 R type cement and glass powder obtained from waste clear glass were used as binders. The chemical compositions of cement and glass powder are given in Table 1, and their physical properties are given in Table 2. The cement used in the mixtures is shown in Figure 1 and the glass powder is in Figure 2.

*Corresponding Author: goksuplsm@gmail.com
Received 13 Dec 2022; Revised 06 Jan 2023; Accepted 06 Jan 2023
https://doi.org/10.36937/cebacom.2023.5773

Table 1. Chemical composition of cement and glass powder

Chemical Composition (%)	Cement	Glass Powder
LOI	4.39	0.70
SiO_2	18.63	71.13
Al_2O_3	4.73	1.57
Fe_2O_3	2.8	0.12
CaO	62.4	8.55
MgO	1.92	4.25
SO_3	3.26	0.08
Na_2O	0.29	12.5
K_2O	0.81	0.14
Na_2O_{eq}	0.82	12.59
Cl-	0.0118	-
TiO_2	-	0.06

Table 2. Physical properties of cement and glass powder

Physical Properties	Cement	Glass Powder
Specific gravity (g/cm^3)	3.08	2.47
Blaine (cm^2/g)	3370	1830
Consistency (%)	28	-
Initial setting time (min)	172	-
Final setting time (min)	281	-
7-day pozzolanic activity index (%)	-	81.8
28-day pozzolanic activity index (%)	-	86.2


Figure 1. Cement


Figure 2. Glass Powder

In the mixtures, fine aggregate of 0-4 mm limestone origin was used. Sieve analysis of limestone aggregate is given in Table 3 and its physical properties are given in Table 4.

Table 3. Sieve analysis of limestone aggregate

Sieve Size (mm)	Passing (%)
4	100.00
2	71.03
1	41.01
0.5	22.96
0.25	12.24
0.125	4.54
0.063	0.74
Pan	0.00

Table 4. Physical properties of limestone aggregate

Physical Properties	Aggregate (0-4 mm)
Compacted bulk density (kg/m^3)	1945
Loose bulk density (kg/m^3)	1693
Oven dry density (g/cm^3)	2.66
Saturated surface dry density (g/cm^3)	2.67
Water absorption (%)	0.69

2.2. Methods

Mixtures within the scope of the study were prepared with a water/binder ratio of 0.5 and an aggregate/binder ratio of 3, by weight. The glass powder used in the mixtures was replaced by weight with cement in 3 different ratios, 5%, 10% and 15%. Samples containing 5%, 10% and 15% glass powder were named CT5, CT10 and CT15, respectively. The mixing ratios of the mortars are given in Table 5.

Table 5. Mixing ratios of mortars

Mix Code	Cement (kg/m^3)	Water (kg/m^3)	Aggregate (kg/m^3)	Glass Powder (kg/m^3)
Control	514	257	1542	-
CT5	486	256	1536	26
CT10	460	255.5	1533	51
CT15	433	255	1530	77

The consistency of the prepared mixtures was determined with the flow table test in accordance with TS EN 1015-3 [19].

For flexural and compressive strength tests, 40x40x160 mm samples produced based on TS EN 196-1 [20]. After casting samples were kept in the curing room for 24 hours. At the end of this period, the samples were taken out of the molds and subjected to water curing in lime-saturated water at 20 ± 1 ℃ until the test day. Flexural and compressive strength tests were carried out for samples reaching 7, 28, 56 and 90 days of curing age.

Horizontal abrasion test was carried out with the samples prepared in 71x71 mm dimensions according to TS 2824 EN 1338 standard [21] for 28 days of curing age.

Capillary water absorption tests were carried out with 40x40x160 mm samples at the 28 days of curing age. The capillary water absorption test was carried out based on the ASTM C1585 [22].

The length changes of the samples produced with prism molds of 25x25x285 mm, which were exposed to 10% sodium sulfate solution for 52 weeks in according to ASTM C1012/C1012M [23].

3. Results

3.1. Flow and density

With the increase in the glass powder ratio in the mixtures, there was an increase up to 5% in flow test values compared to the control mixture. On the other hand, in the CT5 mixture, there was a 1% decrease in flow compared to the control mixture. The flow values of the mixtures are given in Figure 3.

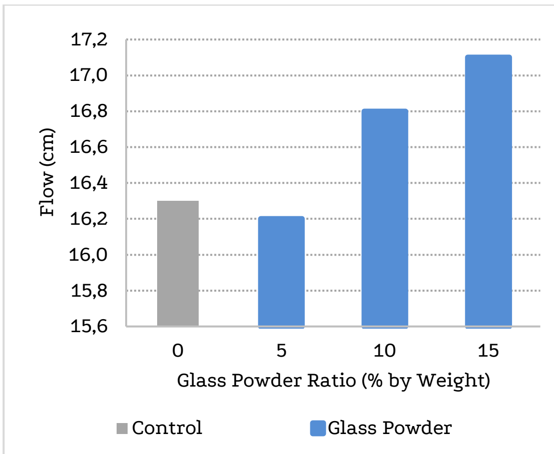

Figure 3. Flow of the mixtures

The saturated surface dry densities of the samples are given in Figure 4, and with the increase of the glass powder ratio in the mixtures, the saturated surface dry density of the samples decreased by 0.5% compared to the control mixture.

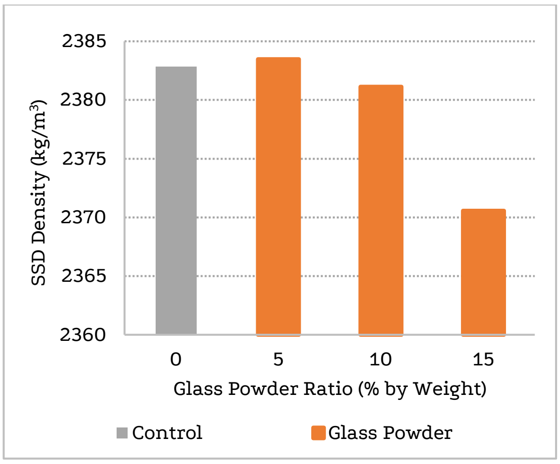

Figure 4. Saturated surface dry density of samples

3.2. Mechanical properties

With the increase in the amount of glass powder in the mixtures, the flexural strength of the samples decreased by 17% and the compressive strength by up to 19%. In the 7-, 28-, 56- and 90-days flexural strength results compared to the control sample, a decrease up to 2%, 4%, 5%, 2% in the CT5 sample and, 7%, 5%, 7%, 5% in the CT10 sample and 17%, 10%, 8%, 7% in the CT15 sample is observed, respectively. Compressive strength test results at the age of 7 and 28 days for CT5 sample compared to control mix, increased for 1% and 0.3%, respectively. And for curing age of 56- and 90-days compressive strength decreased at 9% and 3%, respectively. For the mixtures CT10 and CT15 using glass powder decreased compressive strength of mortars. Compressive strength of glass modified mortars at the age of 7, 28, 56 ang 90 decreased at 5%, 9%, %13, %6, respectively for CT10 mixture. At CT15 mixture decrease in compressive strength compared to control mix at the age of 7, 28, 56 and 90 were at 15%, 12%, 19%, 9%, respectively. The variation of the flexural and compressive strengths of the samples with the glass powder ratio is given in Table 6.

Table 6. Variation of flexural and compressive strength of samples with glass powder ratio

Samples	Flexural Strength (MPa)			
	7 days	28 days	56 days	90 days
Control	10.0	10.4	10.6	10.6
CT5	9.9	10.1	10.1	10.3
CT10	9.4	9.9	9.8	10.1
CT15	8.3	9.4	9.7	9.8
Samples	Compressive Strength (MPa)			
	7 days	28 days	56 days	90 days
Control	49.4	54.5	63.8	60.9
CT5	50.1	54.6	57.8	59.1
CT10	46.8	49.3	55.2	57.2
CT15	42.1	47.8	51.9	55.2

As a result of the abrasion test, the samples containing glass powder lost up to 10% more volume than the control mixture. The volume losses of the samples containing 5%, 10% and 15% glass powder were increased by 8%, 10% and 8%, respectively, compared to the control sample. After abrasion test, the volume losses of the samples are shown in Figure 5.

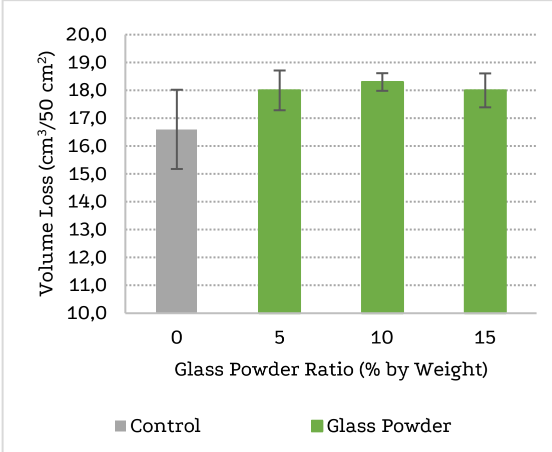

Figure 5. Abrasion volume loss of the samples

3.3. Capillary water absorption

According to the results of the capillary water absorption test, it was observed that the water absorption depths increased with the increase of the glass powder ratio. The water absorption depths of CT5, CT10 and CT15 samples increased by 51%, 62% and 81%, respectively compared to the control mixture. The water absorption values of the samples are given in Figure 6.

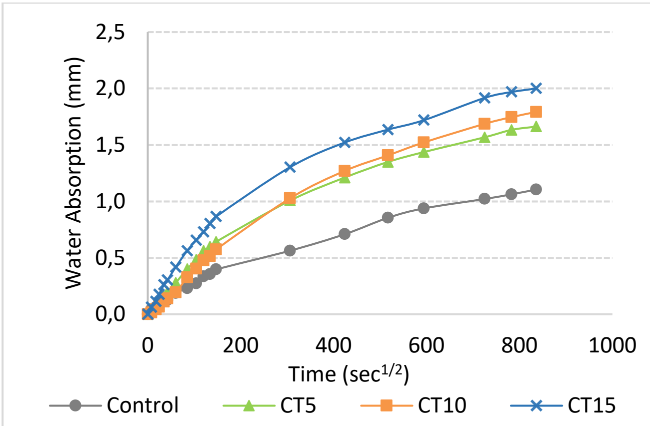

Figure 6. Time dependent water absorption values of samples

3.4. Sulfate resistance

According to the sulphate resistance test results, it was observed that the expansion in the samples was less than the control sample with the increase in the glass powder ratio in the mixtures. At the end of 52 weeks, the expansion of the samples containing 5%, 10% and 15% glass powder was 7%, 13% and 36% less than the control sample, respectively. Sulfate resistance test results are given in Figure 7.

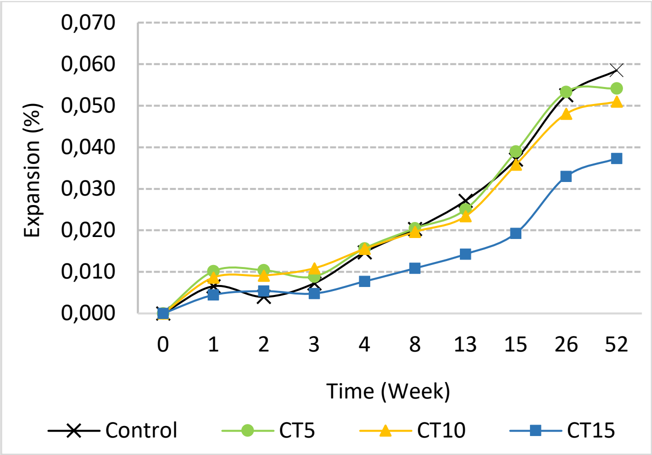

Figure 7. Time dependent expansion of samples by the effect of sodium sulfate

4. Results

The results obtained from this study are listed below:

- With the increase of the glass powder ratio in the mixtures, a decrease of up to 5% in workability and up to 0.5% is observed in SSD densities.
- With the increase of the glass powder ratio, both compressive and flexural strength of the mixes were decreased.
- When the abrasion test results of the samples containing glass powder were compared to the control mixture, it was observed that mixes with glass powder lost up to 10% more volume.
- Mixes with glass powder showed better performance regarding with the capillary water absorption.
- After 52 weeks, mortars produced with glass powder showed less expansion than control mixture.

Declaration of Conflict of Interests

The authors declare that there is no conflict of interest. They have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

[1.] Teng,. G., Hu, Y.M., Behaviour of FRP-jacketed circular steel tubes and cylindrical shells under axial compression. Construction and Building Materials 21 (2007) 827–838.

[2.] Harder, J. (2018). Glass recycling—Current market trends. *Recovery*, *5*.

[3.] Berry, M., Cross, D., & Stephens, J. (2009, May). Changing the environment: an alternative "Green" concrete produced without Portland cement. In *Proc., World of Coal Ash Conf., Lexington, KY, USA*.

[4.] Maraghechi, H., Salwocki, S., & Rajabipour, F. (2017). Utilisation of alkali activated glass powder in binary mixtures with Portland cement, slag, fly ash and hydrated lime. Materials and Structures, 50(1), 1-14.

[5.] Xiao, R., Ma, Y., Jiang, X., Zhang, M., Zhang, Y., Wang, Y., ... & He, Q. (2020). Strength, microstructure, efflorescence behavior and environmental impacts of waste glass geopolymers cured at ambient temperature. *Journal of Cleaner Production*, *252*, 119610.

[6.] Scmidt, A., & Saia, W. H. F. (1963). Alkali-aggregate reaction tests on glass used for exposed aggregate wall panel work. *ACI Mater J*, *60*, 1235-1236.

[7.] Polley, C., Cramer, S. M., & Cruz, R. V. D. L. (1998). Potential for using waste glass in Portland cement concrete. *Journal of materials in Civil Engineering*, *10*(4), 210-219.

[8.] Ling, T. C., & Poon, C. S. (2014). Feasible use of large volumes of GGBS in 100% recycled glass architectural mortar. *Cement and Concrete Composites*, *53*, 350-356.

[9.] Du, H., & Tan, K. H. (2013). Use of waste glass as sand in mortar: Part II–Alkali–silica reaction and mitigation methods. *Cement and Concrete Composites*, *35*(1), 118-126.

[10.] Idir, R., Cyr, M., & Tagnit-Hamou, A. (2011). Pozzolanic properties of fine and coarse color-mixed glass cullet. *Cement and Concrete Composites*, *33*(1), 19-29.

[11.] Pereira-de-Oliveira, L. A., Castro-Gomes, J. P., & Santos, P. M. (2012). The potential pozzolanic activity of glass and red-clay ceramic waste as cement mortars components. *Construction and Building Materials*, *31*, 197-203.

[12.] Federico, L. M., & Chidiac, S. E. (2009). Waste glass as a supplementary cementitious material in concrete–critical review of treatment methods. *Cement and concrete composites*, *31*(8), 606-610.

[13.] Jani, Y., & Hogland, W. (2014). Waste glass in the production of cement and concrete–A review. *Journal of environmental chemical engineering*, *2*(3), 1767-1775.

[14.] Khmiri, A., Chaabouni, M., & Samet, B. (2013). Chemical behaviour of ground waste glass when used as partial cement replacement in mortars. *Construction and building materials*, *44*, 74-80.

[15.] Schwarz, N., & Neithalath, N. (2008). Influence of a fine glass powder on cement hydration: Comparison to fly ash and modeling the degree of hydration. *Cement and Concrete Research*, *38*(4), 429-436.

[16.] Kamali, M., & Ghahremaninezhad, A. (2016). An investigation into the hydration and microstructure of cement pastes modified with glass powders. *Construction and Building Materials*, *112*, 915-924.

[17.] Elaqra, H., & Rustom, R. (2018). Effect of using glass powder as cement replacement on rheological and mechanical properties of cement paste. *Construction and Building Materials*, *179*, 326-335.

[18.] Nahi, S., Leklou, N., Khelidj, A., Oudjit, M. N., & Zenati, A. (2020). Properties of cement pastes and mortars containing recycled green glass powder. *Construction and Building Materials*, *262*, 120875.

[19.] TSE. (2000). TS EN 1015–3, Methods of test for mortar for masonry–Part 3: Determination of consistence of fresh mortar (by flow table).

[20.] Turkish Standard Institute-TSE. (2002). TS EN 196-1: methods of testing cement: part 1: determination of strength.

[21.] Turkish Standard Institute-TSE. (2005). TS 2824 EN 1338: Concrete paving blocks - Requirements and test methods

[22.] ASTM C1585-20 (2020): Standard Test Method for Measurement of Rate of Absorption of Water by Hydraulic-Cement Concretes

[23.] ASTM C1012/C1012M (2019): Standard Test Method for Length Change of Hydraulic-Cement Mortars Exposed to a Sulfate Solution

How to Cite This Article

Pılsım, G., Yavuz, D., and Yazıcı, Ş., An Investigation of Cement Mortars Containing Glass Powder as A Partial Cement Replacement, Cement Based Composites, 1(2023), 5773.
https://doi.org/10.36937/cebacom.2023.5773.