Al-Salam Journal for Engineering and Technology
Journal Homepage: http://journal.alsalam.edu.iq/index.php/ajest
e-ISSN: 2790-4822 p-ISSN: 2958-0862

An investigation into the use of Castable silica waste to produce green mortar

Mohammed Abdul-Kareem Malallah[1]*, Ansam Mishaal Mezaal[2], Mohammed nafaa[3]

[1]School Buildings Department, Nineveh Education Directorate, The Ministry of Education, Al Faisaliah, Mosul, Iraq.
[2]Building & Construction Department, Deputy Dean of Technical Engineering College, Northern Technical University, almajmueat althaqafia, Mosul, Iraq.
[3]State company for agriculture supplies, The Ministry of agriculture, Al Faisaliah, Mosul, Iraq.

*Corresponding Author: Mohammed Abdul-Kareem Malallah

DOI: https://doi.org/10.55145/ajest.2025.04.01.017
Received September 2024; Accepted November 2024; Available online Decemper 2024

ABSTRACT: Cement is a crucial engineering material, and the inclusion of some other substances can alter the characteristics of concrete. Due to the growing tendency to use cement more extensively, it has become imperative to utilize waste resources in order to manufacture environmentally friendly mortar or concrete. Due to the increasing need for eco-friendlier cementitious products, it is becoming increasingly important to assess the pozzolan activity index of prospective materials that can be used as substitutes for cement. The purpose of this research is to present a study that was carried out to evaluate the impact of castable silica waste (CSW) on the development of mortar strength, as well as the optimal usage of mortar CSW and the best substitution ratio in the creation of sustainable mortar. CSW, at three different weight percentages (10%, 20%, 30%), was used as a partial replacement for cement and added superplasticizer SP. A normal mortar using Ordinary Portland cement OPC was constructed to investigate the strength activity index. Cubic mortar samples were fabricated and examined at 7days and 28days. The strength of tests generally increases as the amount of castable silica waste CSW increases up to a certain point. Beyond this point, however, the strength values start to decline with the further addition of CSW. Among the four types of CSW mortars, the most effective amount of cement substitute is around 10%. This is higher than the other green mortars since increasing the amount of CSW decreases compressive strength. The primary objective of this research is to mitigate the carbon dioxide emissions generated by the cement industry and decrease environmentally detrimental waste by utilizing it as a partial substitute for cement.

Keywords: Castable silica waste (CSW), Green mortar, Pozzolan, Strength activity index

1. INTRODUCTION

Fast population growth and the depletion of natural resources have taken the idea of sustainability to the fore. Constant efforts are therefore made to present and improve sustainability in the building sector. To this end, many researchers have focused on the study of concrete because of its versatility and its broad use as construction materials [1]. Cement, an essential ingredient in the production of standard concrete, contributes to the release of carbon dioxide gas. However, this issue can be mitigated by using cement additives throughout the concrete manufacturing process. Cement is the costliest and most energy-intensive type of concrete product. The cost of concrete is decreased by partially substituting business wastes that include high levels of pozzolanic element [2]. Multiple studies have concentrated on identifying alternative materials that can be used as alternatives for cement. Utilizing cement substitute materials is a means of utilizing non-renewable resources and has the potential to significantly advance towards a more environmentally friendly future. Alternative binders to cement can be derived from many sources, including agriculture, industry, and the marine industry. The majority of these materials are traversed by natural or manmade processes [3].

*Corresponding author: moh89kar@gmail.com

Cost-efficient and alternative construction methods can play an essential role in reducing CO_2 emissions by lowering building material quantities by improving and innovative techniques or utilizing alternative materials that consume little energy. Green cement may be characterized as a material solid with a fractional or finished cement alternative. The replacement material may be waste or remaining item in the assembly process. Reduction, reuse and recycling or other concrete technology processes should include green concrete [4].

Through using alternative materials that are less energy-intensive and have lower carbon emissions, such materials include slag, silica fume, rice husk ash, fly ash, and wood ash, castable silica and other waste, this problem can be resolved. CSW is produced as a by-product when pig iron is produced in steel mills [5].

This research used castable silica waste as a replacement for cement and these materials are refractory materials. Refractory castables, which are part of the monolithic family, form a substantial category of materials that have grown in usage significantly over the past three decades. Advancing from basic blends, modern mixes now consist of intricate and specialized compositions employed in a wide range of rigorous and challenging industrial uses. Their market dominance has been growing and, in numerous cases, has surpassed traditional brick-and-mortar refractories. Moreover, it is the most suitable option for multiple applications owing to its superior performance and simplified installation process [6].

Monolithic has quickly surpassed bricks in popularity because of its many advantages, including its low cost, ease of installation, speed, and lack of corrosion-prone lining joints. This all-encompassing word encompasses many materials, from malleable cement pastes to solid plastic balls and many bonding systems. First manufactured in 1914 as a commercial refractory plastic, a basic mixture of fire clay and monolithic materials was initially utilized as a separate refractory product [7].

During operation, metal/CSW propagates into the castables, corroding and eroding the refractory. Some wear mechanisms are thermal shock, iron erosion, and corrosion. Thermal shock can stress refractory castables because of rapid temperature changes. Cracks from these forces shorten refractory life. Molten iron can attack castable elements during oxidation and generate low-melting compounds, degrading their characteristics [8]. And this trash results from disposing of refractory material that was formerly used to line iron melting furnaces or transport molten iron [9]. Therefore, we may use castable silica waste as a partial cement substitute that can be reused rather than disposed of. This paper focuses on finding the Possibility of using castable silica waste as a partial replacement for cement. And the use of the best percentage the produce sustainable mortar.

With the many and increasing challenges to natural resources, it has become necessary to find appropriate solutions to reduce the use of cement, which is a basic material in the construction industry and contributes significantly to carbon dioxide emissions [10,11]. Therefore, it has become necessary to use partial alternatives to cement [12], such as castable silica waste, to reduce the environmental impact, provided that these alternatives do not affect the properties of the durability and strength of the cement mortar.

This research aims to partially replace castable silica waste with mortar production innovation so that it contributes significantly to sustainable construction. It evaluates the impact of waste on mortar properties ranging from strength to durability to determine the waste equivalent ratio for cement replacement, therefore assisting in mitigating CO2 emissions from the conventional cement industry.

This study also addresses sustainability goals in the construction industry by encouraging the use of secondary resources and reducing industrial waste. It stresses the need to improve research on building materials. This would open up possibilities for other waste-related uses and a multi-faceted development of the construction industry as a whole.

2. MATERIALS USED IN STUDY

The base material for specimens is casting consists of cement, sand, water, waste (CSW) and superplasticizers. The following defines its properties and source.

A- Cement: Ordinary Portland cement (OPC) is commonly used as the main binding element in concrete production due to its advantageous adhesive and cohesive properties, which allow it to blend efficiently with other substances. The cement used is locally sourced and belongs to the category of Ordinary Portland cement, namely typeI. [13], they are derived from the Badoush cement mill in the Nineveh Governorate of Iraq. Table 1 displays the physical attributes of cement, and Table 2 lists the chemical components of cement. The physical and chemical parameters of Cement Badoush are according to the "ASTM C150" standard."[14].

Table 1. - Physical characteristics of cement

Test	Results	Limits of ASTM C150
Initial setting time	155 minutes	Min. 45 minute
Initial setting time	325 minutes	Max. 375 minute
Fineness (Blain)	264 m2/kg	Min. 260 m2/kg
Compressive strength of mortar		

3 days	15.62 MPa	Min. 12 MPa
7 days	20.72 MPa	Min. 19 MPa

Table 2. - Chemical compositions of cement

Constituent	Component of Cement (%)	Limits of ASTM C150
SiO_2	21.2	------
Al_2O_3	5.6	------
Fe_2O_3	2.5	------
CaO	62.2	------
MgO	3.8	$\leq$ 6%
SO_3	2.55	$\leq$3.5 if C3A $\geq$ 8%
Loss of ignition	1.65	$\leq$ 3%
Insoluble residue	0.26	$\leq$ 1.5%
Free Cao	1.66	------
L.S.F.	0.88	------
C_3S	34.12	------
C_2S	35.64	------
C_3A	10.75	------
C_4AF	8.49	------

B- Sand: The natural fine aggregate was sourced locally. The sand was collected for this study from a local source in Mosul's Kanhash region, with a specific gravity of sand (2.66), water absorption of (1%) and bulk density (1735 kg/m3), in compatible with ASTM C128-15 [15]. The grading standards for the sand used are compatible with ASTM C33-16 [16]. The table below summarizes the grading standards Table 3.

Table 3. - Grading of (Sand) fine aggregate

NO.	Sieve No. (mm)	Retained (gm)	Retained %	accumulative gm	accumulative %	Passing (%)	Limits of ASTM C 33
1	3⁄8-in. (9.5)	0	0	0	0	100	100
2	No.4 (4.75)	22	4.42	22	4.42	95.58	95-100
3	No.8 (2.36)	70	14.09	92	18.51	81.49	80-100
4	No.16 (1.18)	71	14.29	163	32.79	67.21	50-85
5	No.30 (0.6)	118	23.74	281	56.54	34.46	25-60
6	No.50 (0.3)	125	25.15	406	81.69	18.31	5-30
7	No.100 (0.15)	65	13.08	471	94.77	5.23	0-10
8	No.200 (0.075)	20	4.03	491	98.79	1.21	0-3
9	pan	6	1.2	497	100	0	
Total		497					

C- Water: To mix, clean water from the faucet is used. The water utilized for blending and solidifying must be uncontaminated and devoid of any hazardous oils, acids, alkalis, organic substances, or other detrimental constituents [17]. The same conditions as the mixing water are used to curing the samples.

D- Castable silica waste: Refractories are materials that can withstand high temperatures without being damaged. They are classified as inorganic non-metallic materials. In addition, they should serve other functions, such as reducing heat loss in kilns, transferring heat to the materials inside the kilns, and facilitating the smooth movement of materials through them [18]. and this waste is the by-product of the disposal of refractory material after being used for lining iron melting furnaces or conveying equipment for molten iron. The chemical compositions of castable silica waste are also present in (Table 4).

Table 4. - Chemical compositions of Castable silica waste

Constituent	Component of CSW (%)	Limits of ASTM C150
SiO_2	74.47	------
Al_2O_3	2.1	------
Fe_2O_3	1.9	------
CaO	6.44	------
MgO	0.4	------
SO_3	1	------
Loss of ignition	1.85	------
Insoluble residue	78.73	------
Free Cao	0.14	------
L.S.F.	2.56	------

E- Superplasticizer: The study examines the utilization of Superplasticizers, specifically Flo-Crete SP42, by a DCP firm. These Superplasticizers are advanced fluid concrete admixtures composed of carefully chosen polymers. Their purpose is to enhance the effectiveness of the water content in concrete. This phenomenon can improve the workability and ultimate strengths of the concrete mix by significantly decreasing its water content. The specific gravity of Flo-Crete SP42 ranges from 1.19 to 1.22. The suggested dosage of Flo-Crete SP42 is 0.80 to 2.00 liters per 100 kg of cementitious ingredients in the mix, which includes GGBFS, PFA, or micro-silica [19]. The technical properties of the Floc-rete SP-42 used are also present in (Table 5), And the picture of the superplasticizer show in figure (1).

Table 5. - Technical properties of the Floc-rete SP-42 used

Tests	Results
State of the materials	Liquid
Color	Brown-black
Specific gravity	1.19 - 1.22
Chloride content	Nil
Air entrainment	less than 2%
Structure	sulfonated Naphthalene

FIGURE 1. - Floc-rete SP-42 (5 liters)

3. EXPERIMENTAL PROGRAM

Before they were combined, all materials, including water and superplasticizers, were weighed. Initially, the sand and binders (OPC and castable silica) were thoroughly mixed for approximately 3 minutes, to ensure the castable silica waste was uniformly distributed. The water was progressively applied to the Mortar mix. Water is dispersed uniformly in the dry mixture, a quantity of water is left, and a superplasticizer is added to the remaining water so that the superplasticizers are completely dissolved. The superplasticizer then adds the dissolved water to the mixture. The specimens were produced at the usual size and allowed to remain in the moulds for approximately 24±6 hours. After (24±6) hours, the specimens were dismantled and subjected to the normal curing method of immersing them in a tap water tank at a controlled temperature of 23ºC ±2ºC. The specimens have been tested in a compressive strength test machine (UTM) in compliance with standard testing procedures [20].

Molds used and Specimens: Plastic Cubes were prepared to be applied for mortar tests. 9 cubes of 50x50x50mm were prepared as shown in figure (2).

FIGURE 2. - Cubes of mortar

Mix proportions: During this study, castable silica waste (CSW) was collected from the steel mill Mosul-Iraq. The castable silica waste (CSW) dose used as a partial cement substitute is 10%, 20%, and 30%. Furthermore, a standard mortar that does not contain castable silica waste (CSW) was also prepared and examined to facilitate a comparison of the findings. Therefore, four batches of specimens were fabricated and discussed in this investigation. The study utilized a mortar ratio of 1:2.75 (Cement: Sand), as indicated in Table 6.

Table 6. - mix proportions

percentage of replacement CSW from cement	Binder (500 g)		Sand G	W/C %	Water G	SP. %	SP. G
	Cement G	CSW G					
0%	500	0	1375	0.5	250	0	0
10%	450	50	1375	0.5	270	1	5
20%	400	100	1375	0.45	225	1.2	6
30%	350	150	1375	0.4	200	1.4	7

4. RESULT AND DISCUSSION

A- Flow: The flow table test used to be carried out in conformity with the ASTM C1437 [21]. Table 7 gives water/cement (W/C) ratio, the percentage of superplasticizer in mixes, the reference mortar flow and castable silica waste (CSW) mortar flow.

Table 7.- Flow for specimens

No.	Binder %	Water/cement ratio %	Water Gm	SP. %	SP. gm	Flow mm
1	Cement 100	0.5	250	0	0	110
2	Cement 90+CSW 10	0.45	225	1.1	5.5	109
3	Cement 80+CSW 20	0.42	210	1.3	6.5	113
4	Cement 70+CSW 30	0.4	200	1.5	7.5	110

Table 7 shows clearly that the particles of CSW need more water than cement to obtain roughly the same flow or workability [22]. In this paper, the superplasticizer was added in different proportions according to replacing the cement to get the same flow and the workability. The inclusion of silica fume (CSW) in fresh concrete or mortar decreases its workability due to the cementitious material's extremely high specific surface area [23, 24]. A trial mix method was used to match the workability of the CSW mortar with that of the reference mortar.

B- Strength Activity Index: In compliance with the ASTM C311M [25]. The strength activity index test was carried out. The activity index calculation is shown in Table 8.

Table 8.- Strength Activity Index

Type of specimens	Compressive strength 7 days Mpa	Ave. Strength Activity index 7 days	Compressive strength 28 days Mpa	Ave. Strength Activity index 28 days
Cement 100+CSW 0	19.52	63.88%	29.27	76.39%
Cement 80+CSW 20	12.47		22.36	

The test results show clearly that the CSW strength activity index tends to increase with age increase as shown in figure 1 below [26]. The pozzolanic reaction of silica fume leads to the consumption of calcium hydroxide (CH), which is a hydration product of cement. This facilitates the hydration process, enhancing the extent of cement hydration. In addition, the surfaces of CSW particles with small particle sizes have the potential to serve as nucleation sites for the hydration products of cement, which, therefore, speeds up the process of cement hydration. During this time, the reaction between CSW and CH results in the formation of C–S–H gel. It is possible that the improvement in CSW on the non-vaporable water content can be partially attributed to the increase in the amount of C–S–H gel available [27,28]. Figure 3 presents the strength activity index for castable silica waste (CSW).

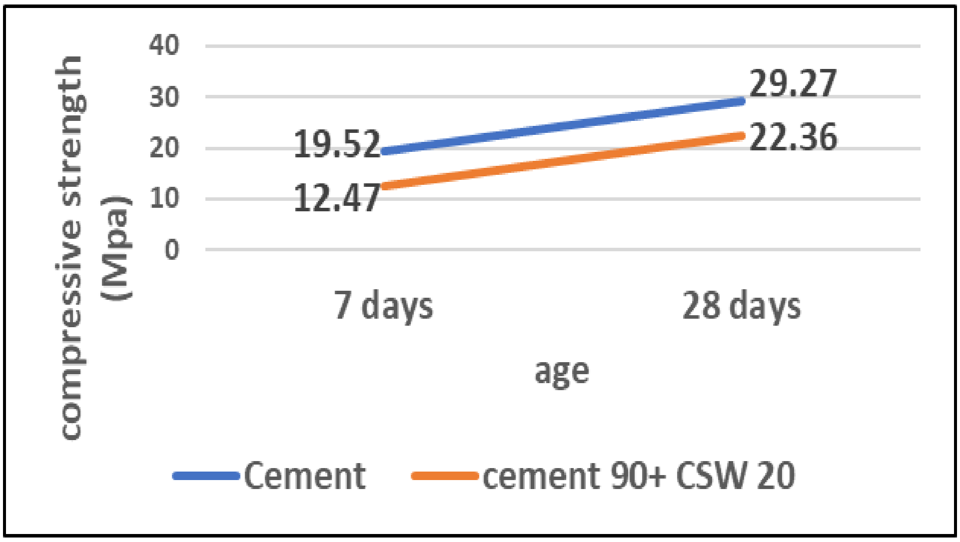

FIGURE 3.- Relationship between compressive strength and age

C- Compressive Strength: The compressive strength test was performed under the ASTM C109/C109M [29]. The computation of compressive strength is shown in table 9 and table 10. must be taken into consideration that the superplasticizer (Flo-Crete SP42) was added to all mixtures containing the CSW in order to improve compressive strength and make workability same in all mixtures.

Compressive strength results for reference mortar and CSW mortar as described in Table 9 below. The tests results showed that the 7 days' compression strength for CSW mortar samples with cement replacement is 10%, 20% and 30%. With an increase in CSW content compared to no CSW mortar, compressive strength is decreased by a curing period of 7 days [30].

It takes longer for mixed cement to reach its early strength than regular cement because it doesn't have enough calcium hydroxide when wet [31].

Table 9.- Compressive Strength at 7 days

days	percentage of replacement CSW from cement	Compressive strength in 7 days Mpa	Average compressive strength Mpa
7	0%	18.24 19.34 19.66	19.08

10%	15.54 15.1 15.36	15.33
20%	12.31 11.63 12.22	12.05
30%	7.85 8.52 7.75	8.04

For reference mortar (OPC) and CSW mortars listed in Table 10 below. The test results indicated that the compressive strength of CSW mortar samples, when substituted with cement, decreased by 10%, 20%, and 30% after 28 days. The 28-day compressive strength of the mortar with 10% substitution of CSW was higher than that of any other replacement mortar. According to this study, the ideal substitute for cement in CSW mortar is 10%. Typically, in the later stages, replacing cement with CSW mortar resulted in increased compressive strength.

When CSW is incorporated into cement, it serves two purposes: firstly, as a chemically inactive substance that enhances the physical composition, and secondly, as a pozzolan that reacts chemically with Calcium Hydroxide (CH) produced during cement hydration and the initiation time of the pozzolanic reaction ranged from 1 day to 28 days, depending on the characteristics of the pozzolana [31]. CSW generates C-S-H gel through its potent pozzolanic activity, resulting in heightened compressive strength and pore filling in cement paste. Consequently, this reduces the cement paste's permeability and improves the mortar's durability [32].

Table 10. - Compressive Strength at 28 days

days	percentage of replacement CSW from cement	Compressive strength in 28 days Mpa	Average compressive strength Mpa
28	0%	27.2 27.5 26.81	27.17
	10%	21.03 22.93 21.12	21.69
	20%	20.82 20.74 19.93	20.49
	30%	14.67 13.92 13.82	14.13

It was predicted that substituting CSW for cement would be somewhat similar to the 28-day compressive strength. This happened because the cement-hydration process generated calcium silicate hydrate (C-S-H) when the silica fume reacted with calcium hydroxide. It was also because of the filling function of excellent silica fume particles [33].

5. CONCLUSION

The following conclusion can be formed based on the limited experimental research conducted regarding the flow test, activity index test, and compressive strength of concrete that contained castable silica waste (CSW) as a partial substitute for cement.

• The CSW needs more water than the reference mixture (0% CSW). It is to be noted that the excess water needed by the CSW has to be replaced by the addition of the superplasticizer, while the water percentage remains constant in all mixtures.

• The strength activity index of CSW in 7 days is 63.88% and the strength activity index of CSW in 28 days is 76.39%. Thus, the CSW is more effective at later ages. The poor activity of CSW at early ages can be overcome by the addition of superplasticizers.

• By conducting practical experiments in the laboratory, the results showed, The lower the cement replacement ratio with CSW, the greater the compressive strength at early and late ages. The use of 10% of CSW as a partial replacement of cement is the highest reliable replacement ratio for producing sustainable mortar that can be used. This percentage is the ideal replacement ratio because the cement substitution percentage corresponds with the added superplasticizer percentage, giving more of the highest compressive strength than other replacement ratios.

• Utilizing castable silica waste as a partial cement substitute greatly advances sustainability, diminishes carbon dioxide emissions, promotes the use of secondary resources, and mitigates industrial waste. This will create opportunities for utilizing alternative secondary materials to enhance sustainability in the construction industry.

FUNDING

None

ACKNOWLEDGEMENT

We are grateful to everyone who provided support to make this work a success. Thank you.

CONFLICTS OF INTEREST

The authors declare no conflict of interest

REFERENCES

[1] M. L. Ahmed, M. A. Javed, and A. S. Qureshi, “Benefits of incorporating induction furnace slag in concrete as replacement of cement: A case study of Pakistan,” Mehran University Research Journal of Engineering and Technology, vol. 37, no. 4, pp. 701–714, 2018, doi: 10.22581/muet1982.1804.20.

[2] S. Elavarasan, A. K. Priya, N. Ajai, S. Akash, T. J. Annie, and G. Bhuvana, “Experimental study on partial replacement of cement by metakaolin and GGBS,” Materials Today: Proceedings, no. xxxx, pp. 3–6, 2020, doi: 10.1016/j.matpr.2020.09.416.

[3] E. Aprianti S, “A huge number of artificial waste material can be supplementary cementitious material (SCM) for concrete production – A review part II,” Journal of Cleaner Production, vol. 142, pp. 4178–4194, 2017, doi: 10.1016/j.jclepro.2015.12.115.

[4] “Utilization of iron and steel slag in building construction,” IOP Conference Series: Materials Science and Engineering, vol. 020032, no. September 2019, 2020.

[5] P. Nagarajan and A. P. Shashikala, “Ecofriendly GGBS concrete: A state-of-the-art review,” IOP Conference Series: Materials Science and Engineering, no. July, 2019, doi: 10.1088/1757-899X/330/1/012057.

[6] M. Nouri-khezrabad, M. A. L. Braulio, V. C. Pandolfelli, and F. Golestani-fard, “Nano-bonded refractory castables,” Ceramics International, vol. 39, no. 4, pp. 3479–3497, 2013, doi: 10.1016/j.ceramint.2012.11.028.

[7] W. E. Lee, W. Vieira, S. Zhang, K. G. Ahari, H. Sarpoolaky, and C. Parr, “Castable refractory concretes,” Journal of Materials Science, vol. 46, no. 3, pp. 145–167, 2001.

[8] V. Pilli and R. Sarkar, “Effect of spinel content on the properties of Al2_22O3_33-SiC-C based trough castable,” Ceramics International, 2015, doi: 10.1016/j.ceramint.2015.10.081.

[9] E. Getachew, B. Worku, and M. Yehualaw, “The use of ground recycled concrete cement as an eco-friendly alternative cement material in mortar production,” Iranian Journal of Science and Technology - Transactions of Civil Engineering, vol. 48, Aug. 2024, doi: 10.1007/s40996-024-01606-3.

[10] I. Shah, S. Miller, D. Jiang, and R. Myers, “Cement substitution with secondary materials can reduce annual global CO2_22 emissions by up to 1.3 gigatons,” Nature Communications, vol. 13, p. 5758, Sep. 2022, doi: 10.1038/s41467-022-33289-7.

[11] A. K. Chishi and L. Gautam, “Sustainable use of silica fume in green cement concrete production: A review,” Innovative Infrastructure Solutions, vol. 8, no. 7, p. 195, 2023, doi: 10.1007/s41062-023-01164-z.

[12] H. M. Hamada et al., “Effect of silica fume on the properties of sustainable cement concrete,” Journal of Materials Research and Technology, vol. 24, pp. 8887–8908, 2023, doi: 10.1016/j.jmrt.2023.05.147.

[13] A. A. Phul, M. J. Memon, S. N. R. Shah, and A. R. Sandhu, “GGBS and fly ash effects on compressive strength by partial replacement of cement concrete,” Civil Engineering Journal, vol. 5, no. 4, pp. 913–921, 2019, doi: 10.28991/cej-2019-03091299.

[14] ASTM C150/150M-17, “Standard specification for Portland cement,” Annual Book of ASTM Standards, vol.i, no. Reapproved, pp. 1–4, 2017, doi: 10.1520/C0150.

[15] ASTM C128-15, “Standard test method for relative density (specific gravity) and absorption of fine aggregates,” ASTM International, vol. i, pp. 15–20, 2015, doi: 10.1520/C0128-15.2.

[16] ASTM C33/C33M−16, “Standard specification for concrete aggregates,” Annual Book of ASTM Standards, vol. i, no. C, pp. 1–11, 2016, doi: 10.1520/C0033.

[17] A. Sk, "Investigation on strength and durability of concrete by partial replacement of GGBS in cement," no. January 2019, 2020.
[18] I. M. I. Bayoumi, E. M. M. Ewais, and A. A. M. El-Amir, "Rheology of refractory concrete: An article review," Boletín de la Sociedad Española de Cerámica y Vidrio, pp. 1–17, 2021, doi: 10.1016/j.bsecv.2021.03.003.
[19] F. SP42, "Flocrete SP42 Flocrete SP42."
[20] A. E. Sciences, "Effect on the compressive strength of mortars using ground granulated blast furnace slag as a partial replacement of cement," no. December, 2019, doi: 10.2478/jaes-2019-0025.
[21] ASTM, "C1437 - Standard test method for flow of hydraulic cement mortar," ASTM International, pp. 1–2, 2013, doi: 10.1520/C1437-15.2.
[22] M. Sarıdemir, "Effect of silica fume and ground pumice on compressive strength and modulus of elasticity of high strength concrete," vol. 49, pp. 484–489, 2013, doi: 10.1016/j.conbuildmat.2013.08.091.
[23] A. Mehta and D. K. Ashish, "Silica fume and waste glass in cement concrete production: A review," Journal of Building Engineering, p. 100888, 2019, doi: 10.1016/j.jobe.2019.100888.
[24] A. Kılıc, O. Karahan, C. Bilim, and M. H. Severcan, "Influence of dry and wet curing conditions on compressive strength of silica fume concrete," vol. 40, pp. 1678–1683, 2005, doi: 10.1016/j.buildenv.2004.12.005.
[25] ASTM C311/C311M−16, "Standard test methods for sampling and testing fly ash or natural pozzolans for use in Portland-cement concrete," Annual Book of ASTM Standards, vol. 04.02, pp. 204–212, 2016, doi: 10.1520/C0311.
[26] S. Donatello, M. Tyrer, and C. R. Cheeseman, "Comparison of test methods to assess pozzolanic activity," Cement and Concrete Composites, vol. 32, no. 2, pp. 121–127, 2010, doi: 10.1016/j.cemconcomp.2009.10.008.
[27] Z. Zhang, B. Zhang, and P. Yan, "Comparative study of effect of raw and densified silica fume in the paste, mortar, and concrete," Construction and Building Materials, vol. 105, pp. 82–93, 2016, doi: 10.1016/j.conbuildmat.2015.12.045.
[28] R. Terje and T. Per, "Inconsistencies in the pozzolanic strength activity index (SAI) for silica fume according to EN and ASTM," Materials and Structures, pp. 3979–3990, 2015, doi: 10.1617/s11527-014-0457-6.
[29] ASTM C109M-02, "Standard test method for compressive strength of hydraulic cement mortars," Annual Book of ASTM Standards, vol. 04, pp. 1–6, 2007, doi: 10.1520/C0109.
[30] I. Sezer, "Compressive strength and sulfate resistance of limestone and/or silica fume mortars," vol. 26, pp. 613–618, 2012, doi: 10.1016/j.conbuildmat.2011.06.064.
[31] D. Rus, D. Vez, R. Krstulovic, and J. Zelic, "The role of silica fume in the kinetics and mechanisms during the early stage of cement hydration," vol. 30, pp. 1655–1662, 2000.
[32] M. Rostami and K. Behfarnia, "The effect of silica fume on durability of alkali activated slag concrete," Construction and Building Materials, vol. 134, pp. 262–268, 2017, doi: 10.1016/j.conbuildmat.2016.12.072.
[33] R. Siddique, "Utilization of silica fume in concrete: Review of hardened properties," Resources, Conservation and Recycling, vol. 55, no. 11, pp. 923–932, 2011, doi: 10.1016/j.resconrec.2011.06.012.