ASSESS THE POSSIBILITY OF USING RECYCLED GLASS AND CERAMIC FOR PREPARING ARCHITECTURAL MORTAR

Md. Waliullah[1], Pratyo Goswami[2], Jamiul Kawsar Rishad[3] and Md. Mahmudur Rahman[4*]

[1] *Undergraduate Student, Bangladesh Army University of Engineering and Technology, Bangladesh. e-mail:*
mdwaliullah7272@gmail.com
[2] *Undergraduate Student, Bangladesh Army University of Engineering and Technology, Bangladesh, e-mail:*
pratyo.goswami.12@gmail.com
[3] *Undergraduate Student, Bangladesh Army University of Engineering and Technology, Bangladesh, e-mail:*
jamiulrishad@gmail.com
[4] *Associate Professor, Bangladesh Army University of Engineering and Technology, Bangladesh, e-mail:*
drmahmudur.rits@gmail.com

***Corresponding Author**

ABSTRACT

The production of industrial waste has been steadily rising as a result of the ongoing demands for resources by humans, and this industrial waste can be used in mortar or concrete to replace cement or aggregate. Annually, around 130 million tons of glass are produced around the world, of which only 21% is recycled, mostly container glass. Each year, 1.5 million tonnes of ceramic waste come from manufacturers, and 30% of ceramic materials are turned into waste due to improper handling and poor skill at construction sites. Both waste glass and ceramic powder possess good workability and compressive strength. The objective of this research was to develop a mortar for architectural applications that combines glass and ceramic powders and assess its possibility as a combination of waste ceramic and glass powder in mortar or concrete has not been investigated yet. The waste ceramics were collected from building construction, and waste glass collected from recycled shops was used in this study. Both waste ceramic and glass were crushed to form powder and sieved for further use. Fine sand was replaced by ceramic powder (denoted as C), and conventional Ordinary Portland cement (OPC) Type I was replaced with glass powder (denoted as G). The standard consistency test, setting time test, 7,14- and 28-days compressive strength test, and Scanning Electron Microscopy (SEM) test were carried out. It was found that the consistency of cement paste increased by 1.5 ~ 7%, and setting time increased by 5-34% as the glass powder content increased. The compressive strength was increased due to glass and ceramic powder. The maximum compressive strength was found in C20G5, which was 13.66% and 8% higher than CM for 14 and 28 days, respectively. The SEM photograph shows no crack and void for C10G5, C20G5, C10G10 and C20G10.

Keywords: *Recycled glass, recycled ceramic, mortar, architectural mortar, thermal insulation*

1. INTRODUCTION

The production of the industrial waste has been steadily rising as a result of the ongoing demands for resources by humans and this industrial waste can be used in mortar or concrete to replace cement or aggregate (Torkittikul & Chaipanich, 2010). Glass containers are frequently used for packaging beverages because of their visual clarity, chemical inertness, high inherent strength, and low gas permeability (Lu et al., 2017), and have high silica content, as shown in Table 1. Annually, around 130 million tons of glass are produced around the world, of which only 21% is recycled, mostly container glass (Ani *et al.*, 2022). In Bangladesh, around 14,770 tons of glass waste are produced every year, with a market value of $249,550 (Sobuz *et al.*, 2023). The majority of recycled container glass in Europe is used to make new glass, which puts the recycling rate at 74%.. However, due to the lack of a glass manufacturing industry, the bulk of used glass containers in Asia are thrown in landfills rather than recycled (Xin Lu *et al.*, 2017). Only 12% of discarded glass was recycled, which was substantially lower than in Europe (Sobuz *et al.*, 2023).

Table 1: Chemical composition of cement, glass powder, and ceramic powder (%weight)

Compound	**Composition**		
	Cement (adopted from Lu *et al.*, 2017)	Glass powder (adopted from Lu *et al.*, 2017)	Ceramics powder (adopted from Olawale & Tijani 2018)
SiO_2	21.36	73.5	64.56
Al_2O_3	5.27	0.73	15.07
Fe_2O_3	0.20	0.38	6.01
CaO	67.49	10.48	4.15
MgO	1.14	1.25	2.04
K_2O	0.077	0.69	2.13
Na_2O	0.048	12.74	-
TiO_2	0.14	0.087	-
SO_3	2.60	-	-
$SiO_2 + Al_2O_3 + Fe_2O_3$	26.83	74.61	85.64

Glass waste recycling has gained popularity recently as a way to use recycled glass in concrete and mortar instead of aggregates or cement (Muhedin & Ibrahim, 2023; Kalakada *et al.*, 2019; Elaqra *et al.*,2019; Aliabdo *et al.*, 2016). Researchers argue about the effect of glass aggregate on the workability of concrete when used as a replacement for aggregates in mortar and concrete. Several studies found that when the percentage of glass particles in fresh concrete climbed, the slump value of the material was reduced, which led to poor workability (Wang, 2009; Ismail & Al-Hashmi, 2009). In contrast, Zhao *et al*., (2013) found that substituting natural aggregates with waste glass resulted in enhanced workability, attributed to the non-absorbent properties of glass. The particle size of glass aggregates used as replacement aggregates has a significant impact on the rate of hydration (Ling *et al.*, 2011). The addition of glass aggregates to cement-based products significantly enhances their durability by improving surface resistivity and resistance to sulfate attack (Wang, 2009). The more glass particles there were in the concrete, the less permeable to the chloride ions and more drying shrinkage (Kou & Poon, 2009). The reactivity of glass powder is influenced by its chemical composition and fineness (Hosseini & Riding, 2015). As glass powder particle size reduces, cement-glass mixes tend to become stronger (Schwarz & Neithalath, 2008). Several investigations have confirmed that the compressive strength first increases until it reaches an acceptable criterion when a certain percentage substitute is achieved but thereafter decreases (Aliabdo *et al.,* 2016). In comparison to the control cement paste, it was found that adding glass powder to the cement paste significantly increased its electrical resistivity (Kamali & Ghahremaninezhad, 2016).

Ceramics are manufactured by using clay or China clay, which is subjected to firing at temperatures ranging from 1000 to 1150 °C (Torkittikul & Chaipanich, 2010). Ceramic tile wastes from construction sites, manufacturing plants, and building demolition projects pose an environmental issue as they pollute land and water by practicing landfilling. Each year, 1.5 million tonnes of ceramic waste come from manufacturers. Also, 30% of ceramic materials turned into waste due to improper handling and poor skill at construction sites (Lim *et al.,* 2022). Ceramic waste possesses numerous advantageous characteristics, including its hardness, durability, and exceptional resistance to pollutants. The qualities of ceramic waste make it possibly suitable for incorporation into mortar. Ceramics that are crushed have a smaller size compared to ceramics used as electrical insulators, and they do not pose any problems with water absorption (Torkittikul & Chaipanich, 2010). Also, ceramic powder has CaO (Table 1), which is a cementitious material that enhances compressive strength. Ceramic waste has a lower specific mass than sand and increases water consumption in the mortar and workability (Cherene *et al.*, 2023). Many researchers used ceramic wastes as fine aggregate (Tanash *et al.,* 2023; Hamad *et al.*, 2020; Mohammadhosseini *et al.*, 2019).

It was found from the above literature that previous studies were carried out for waste glass powder and waste ceramic powder, each replacing cement and aggregate material separately. However, using a combination of waste ceramic and glass powder in mortar or concrete has not been investigated yet. Hence, the objective of this research was to develop a mortar for architectural applications that combines glass and ceramic powders and assess its possibility.

2. METHODOLOGY

2.1 Materials

The waste ceramics were collected from building construction, and waste glass was collected from recycled shops. Both waste ceramic and glass were crushed to form powder and sieved for further use. For ceramic powder, 70% of the 1.18 mm sieve retainer and 30% of the 2.36 mm retainer were used. Meanwhile, for glass powder, 90% of 600-micron sieve passing, 300-micron sieve retainer, and 10% of 300-micron sieve passing were used. In order to investigate the feasibility of replacing fine sand with ceramic powder (denoted as C) and conventional Ordinary Portland cement (OPC) Type I with glass powder (denoted as G), several combinations of mix proportion were prepared, which were shown in Table 2. Also, a regular mortar (denoted as CM) was prepared using Ordinary Portland cement (OPC) Type I and fine sand. The water-cement (W/C) ratio for each mix proportion was used at 0.52, and the cement: sand ratio was used at 1:2.75.

Table 2: Mix proportions of different mixture

Mix ID	Ceramic powder (%) to replace sand	Glass powder (%) to replace OPC Type I
CM	-	-
C10G5	10	5
C10G10	10	10
C10G15	10	15
C10G20	10	20

C10G25	10	25
C20G5	20	5
C20G10	20	10
C20G15	20	15
C20G20	20	20
C20G25	20	25

2.2 Laboratory Test

The standard consistency test (ASTMC187, 2016) and setting time test (ASTM C191, 2016) for cement paste were carried out for different combinations by replacing cement with glass powder by 5% (denoted as G5), 10% (denoted as G10), 15% (denoted as 15), 20% (denoted as G20) and 25% (denoted as G25). The compressive strength test (ASTMC109) of different mortar mixes (Table 1) was carried out for 7-, 14-, and 28-day samples. All the tests were done in the department laboratory at the university premises. All the data were analysed using Microsoft Excel 2021. The scanning electron microscopy (SEM) investigation was conducted at the Bangladesh Council of Scientific and Industrial Research (BCSIR) using the 30KV VP-SEM machine.

3. RESULT AND DISCUSSION

3.1 Standard Consistency

It was seen from Figure 1 that the consistency of cement paste increased by 1.5 ~ 7% as the glass powder content increased. Khan et al. (2020) reported that the increase in water requirement was found when cement replacing material has low specific gravity and higher specific surface area. It was known that glass powder has a lower specific gravity than cement, which increases water requirements (Deshmukh & Deshmukh, 2014; Miranda et al., 2014). Also, Alshamsi et al. (1993) mentioned that silica present in glass powder and small particle sizes of glass powder increase water demand. The consistency test results were found to be similar to those of previous researchers, where it was found that water requirement was increased by replacing cement with silica fume (Rao, 2003) and silica content (Qing et al., 2007).

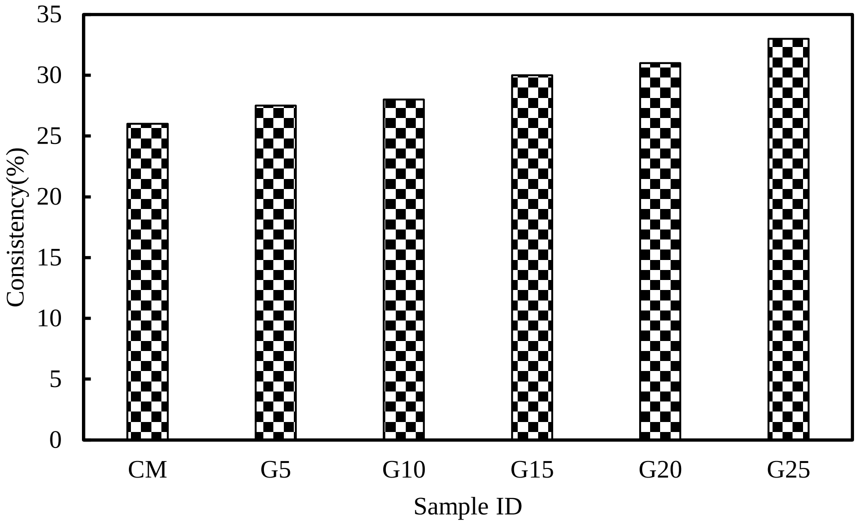


Figure 1: Standard consistency of cement paste (with different % of glass powder replacement)

3.2 Initial and Final Setting Times

This study examines the differences in the start and final setting time of the cement paste with different % of glass powder replacement. From Figure 2, it was seen that, by increasing glass powder content to replace cement, setting time was increased, which ranged from 5-34%. Similar results were found by other researchers (Lu *et al.,* 2017*;* Alshamsi *et al.,* 1993), where it was found that waste glass powder or micro-silica increases the setting time as it was a pozzolanic material that reacts with hydration time.

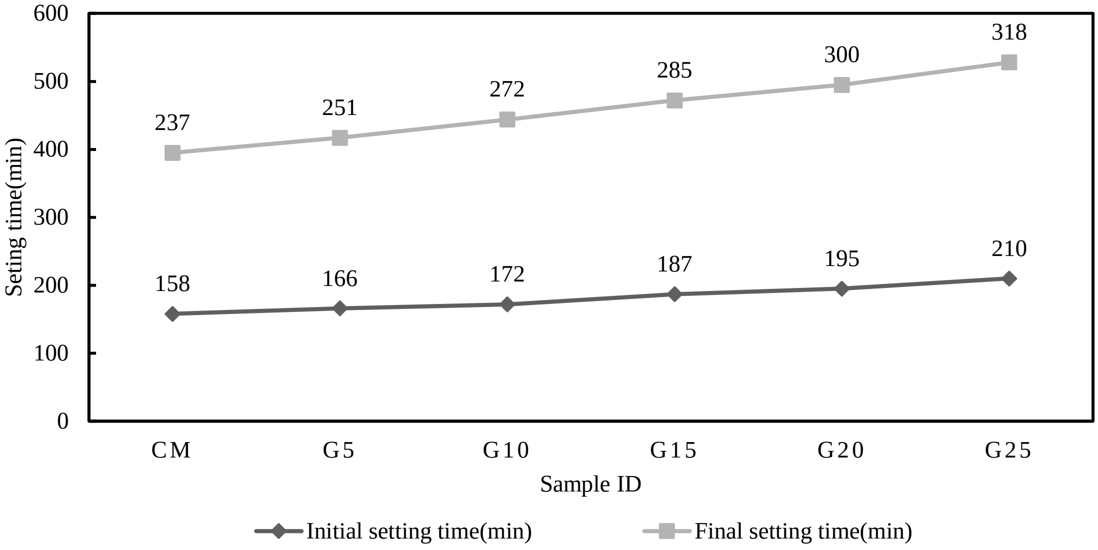


Figure 2: Setting time of cement paste (with different % of glass powder replacement)

3.3 Compressive Strength

Figure 3 shows the effects on the compressive strength of mortars at 7, 14, and 28 days of substituting cement with glass powder at different percentages (5~25%) and utilizing ceramic powder as a replacement of sand at 10% and 20% by weight. Although the compressive strength of mortar generally decreased due to the replacement of cement or sand, similar to Ozkan & Yüksel (2008), it was found that for 14 and 28 days, the maximum compressive strength was found in C20G5, which was 13.66% and 8% higher than CM, respectively. Meanwhile, for 7 days, the maximum compressive strength was found in C20G10, which was 10.10% higher than CM and 13% higher than C20G5. Also, the compressive strength was similar to CM for 7 days were C10G5, C10G10, C20G5, and C20G15. The compressive strength was increased more than CM for 14 days, which were C10G5, C10G10, and C20G10; for 28 days, it was C20G10. The increase in compressive strength may be caused by glass powder, as Rao (2003) reported that the presence of silica reduced the calcium hydroxide content of cement, which increased the strength. Also, ceramic powder increased the compressive strength if it replaced the sand upto 50% (Torkittikul et al., 2010).

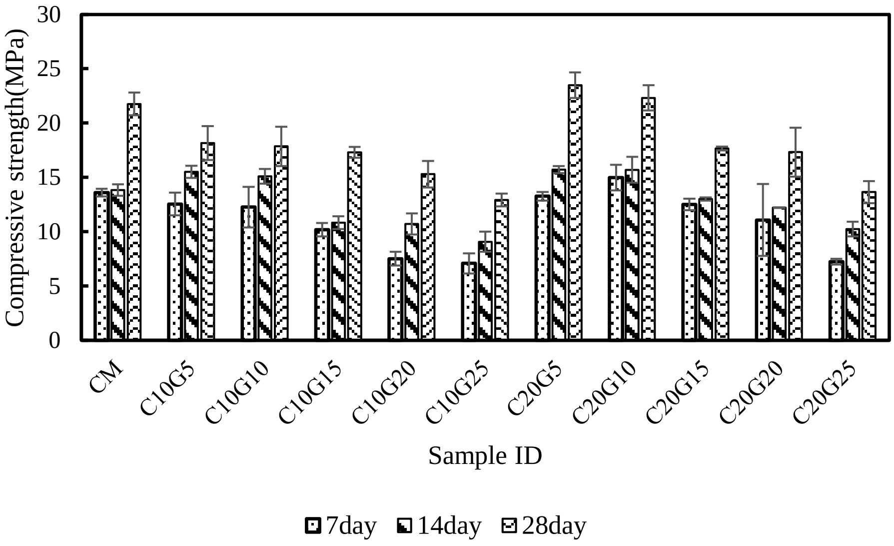
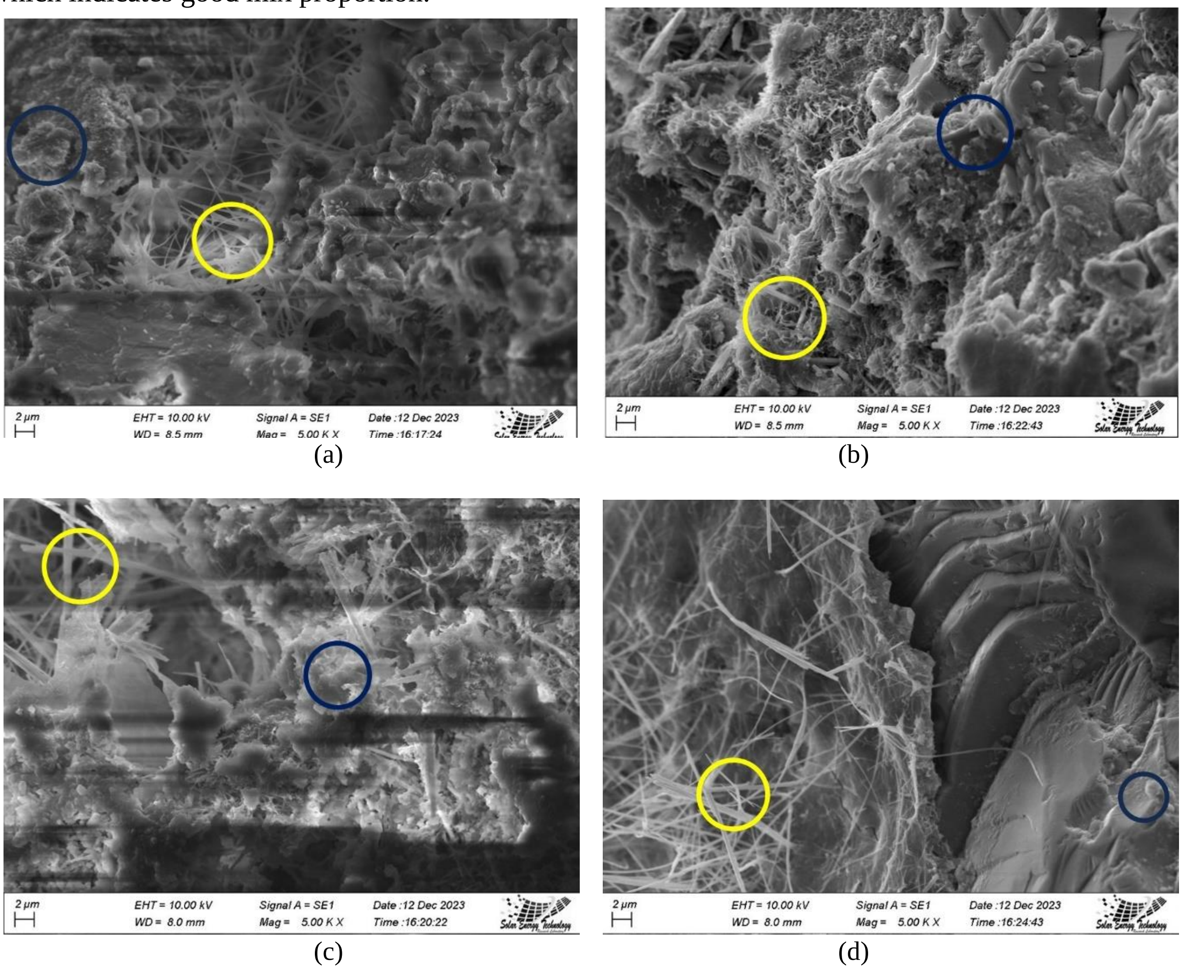


Figure 3: Compressive strength test

3.4 Scanning Electron Microscope (SEM)

Figure 4 shows the Scanning Electron Microscope (SEM) photograph, where the yellow circle indicates the glass powder and blue indicates the ceramic powder. There was no crack observed among the four samples C10G5, C20G5, C10G10 and C20G10. All samples pose no significant void, which indicates good mix proportion.



(a) (b)

(c) (d)

Figure 4: SEM image for replecement (a) C10G5, (b) C20G5, (c) C10G10, (d) C20G10

4. CONCLUSIONS

The findings of this study were summarized as follows:

- The consistency of cement paste increased by 1.5 ~ 7% as the glass powder content increased.
- By increasing glass powder content to replace cement, setting time was increased, which ranged from 5-34%.
- The compressive strength was increased due to glass and ceramic powder. The maximum compressive strength was found in C20G5, which was 13.66% and 8% higher than CM for 14 and 28 days, respectively. Also, the maximum compressive strength was found in C20G10, which was 10.10% higher than CM and 13% higher than C20G5 for 7 days.
- The SEM photograph shows no crack and void for C10G5, C20G5, C10G10 and C20G10

It can be concluded that using glass and ceramic powder produced from recycled glass and ceramic has the potential to be used as architectural mortar. However, further work needs to be done to understand the combined effect of glass and ceramic powder in mortar.

REFERENCE

Aliabdo, A. A., Abd Elmoaty, M., & Aboshama, A. Y. (2016). Utilization of waste glass powder in the production of cement and concrete. *Construction and Building Materials*, 124, 866-877.

Alshamsi, A. M., Sabouni, A. R., & Bushlaibi, A. H. (1993). Influence of set-retarding superplasticisers and microsilica on setting times of pastes at various temperatures. *Cement and Concrete Research*, 23(3), 592-598.

Ani, F. M., Hossain, M. A., & Shahril, R. N. (2022). Recycling of glass waste on the concrete properties as a partial binding material substitute. *European Journal of Engineering and Technology Research*, 7(6), 138-142. https://doi.org/10.24018/ejeng.2022.7.6.2940

ASTM C109. (2016). ASTM C109/C109M-16a: Standard Test Method for Compressive Strength of Hydraulic Cement Mortars (Using 2-in. or [50-mm] Cube Specimens). West Conshohocken, PA.

ASTM C187. (2016). ASTM C187-16: Standard Test Method for Amount of Water Required for Normal Consistency of Hydraulic Cement Paste. West Conshohocken, PA.

ASTM C191. (2016). ASTM C191-21: Standard Test Methods for Time of Setting of Hydraulic Cement by Vicat Needle. West Conshohocken, PA.

Cherene, M. G., Xavier, G. D., Barroso, L. D., Oliveira, J. D., Azevedo, A. R., Vieira, C. M., Alexandre, J., & Monteiro, S. N. (2023). Technological and microstructural perspective of the use of ceramic waste in cement-based mortars. *Construction and Building Materials*, 367, 130256. https://doi.org/10.1016/j.conbuildmat.2022.130256

Deshmukh, P. S. M., & Deshmukh, R. Y. M. (2014). Comparative Study of Waste Glass Powder Utilized In Concrete. *International Journal of Science and Research (IJSR)*, 3(12), 1457-1458. https://www.ijsr.net/

Elaqra, H. A., Haloub, M. A., & Rustom, R. N. (2019). Effect of New Mixing Method of Glass Powder as Cement Replacement on Mechanical Behavior of Concrete. *Construction and Building Materials*, 203, 75-82. https://doi.org/10.1016/j.conbuildmat.2019.01.077

Hamad, A. J., Sldozian, R. J., & A. Mikhaleva, Z. (2020). Effect of Ceramic Waste Powder as Partial Fine Aggregate Replacement on Properties f Fiber-Reinforced Aerated Concrete. *Engineering Reports*, 2(3). https://doi.org/10.1002/eng2.12134

Ismail, Z. Z., & Al-Hashmi, E. A. (2009). Recycling of Waste Glass As A Partial Replacement for Fine Aggregate in Concrete. *Waste Management*, 29(2), 655-659. https://doi.org/10.1016/j.wasman.2008.08.012

Kalakada, Z., Doh, J., & Chowdhury, S. (2019). Glass Powder as Replacement of Cement for Concrete – An Investigative Study. *European Journal of Environmental and Civil Engineering*, 26(3), 1046-1063. https://doi.org/10.1080/19648189.2019.1695149

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.

Khan, K., Ullah, M. F., Shahzada, K., Amin, M. N., Bibi, T., Wahab, N., & Aljaafari, A. (2020). Effective use of micro-silica extracted from rice husk ash for the production of high-performance and sustainable cement mortar. *Construction and Building Materials*, 258, 119589.

Khan, K., Ullah, M. F., Shahzada, K., Amin, M. N., Bibi, T., Wahab, N., & Aljaafari, A. (2020). Effective use of micro-silica extracted from rice husk ash for the production of high-performance and sustainable cement mortar. *Construction and Building Materials*, 258, 119589. https://doi.org/10.1016/j.conbuildmat.2020.119589

Kou, S. C., & Poon, C. S. (2009). Properties of self-compacting concrete prepared with recycled glass aggregate. *Cement and Concrete Composites*, 31(2), 107-113.

Le Bourhis, E. (2014). *Glass: mechanics and technology*. John Wiley & Sons.

Lim, S. K., Lee, Y. L., Yew, M. K., Ng, W. W., Lee, F. W., Kwong, K. Z., & Lim, J. H. (2022). "Mechanical Properties of Lightweight Foamed Concrete With Ceramic Tile Wastes as Partial Cement Replacement Material". Frontiers In Built Environment, 8. https://doi.org/10.3389/fbuil.2022.836362

Ling, T. C., Poon, C. S., & Kou, S. C. (2011). Feasibility of using recycled glass in architectural cement mortars. *Cement and Concrete Composites*, 33(8), 848-854.

Lu, J. X., Duan, Z. H., & Poon, C. S. (2017). Fresh properties of cement pastes or mortars incorporating waste glass powder and cullet. *Construction and Building Materials*, 131, 793-799.

Miranda Jr., E. J., Paiva, A., & Rodrigues, E. N. (2014). "Influence of waste glass on the physical properties of Portland cement concrete." Materials Science Forum, 798-799, 576-581. https://doi.org/10.4028/www.scientific.net/msf.798-799.576

Mohammadhosseini, H., Lim, N. H., Tahir, M. M., Alyousef, R., Samadi, M., Alabduljabbar, H., & Mohamed, A. M. (2019). Effects of waste ceramic as cement and fine aggregate on durability performance of sustainable mortar. *Arabian Journal for Science and Engineering*, 45(5), 3623-3634. https://doi.org/10.1007/s13369-019-04198-7

Muhedin, D. A., & Ibrahim, R. K. (2023). "Effect of waste glass powder as partial replacement of cement & sand in concrete." Case Studies in Construction Materials, 19, e02512. https://doi.org/10.1016/j.cscm.2023.e02512

Nazari, A., & Riahi, S. (2011). RETRACTED: The effects of SiO2 nanoparticles on physical and mechanical properties of high strength compacting concrete.

Olawale, S. O.A. & Tijani, M. A. (2018). Mechanical Properties of Concrete Produced from Partial Replacement with Ceramic Tile Wastes. *Journal of Research Information in Civil Engineering*, 15(3), 2245-2255.

Qing, Y., Zenan, Z., Deyu, K., & Rongshen, C. (2007). Influence of nano-SiO2 addition on properties of hardened cement paste as compared with silica fume. *Construction and building materials*, 21(3), 539-545.

Rahman Sobuz, M. H., Meraz, M. M., Safayet, M. A., Mim, N. J., Mehedi, M. T., Noroozinejad Farsangi, E., Shrestha, R. K., Kader Arafin, S. A., Bibi, T., Hussain, M. S., Bhattacharya, B., Aftab, M. R., Paul, S. K., Paul, P., & Meraz, M. M. (2023). Performance Evaluation of High-Performance Self-Compacting Concrete with Waste Glass Aggregate and Metakaolin. *Journal of Building Engineering*, 67, 105976. https://doi.org/10.1016/j.jobe.2023.105976

Rao, G. A. (2003). Investigations on the performance of silica fume-incorporated cement pastes and mortars. *Cement and Concrete Research*, 33(1765–1770).

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.

Shelby, J. E. (2020). Introduction to glass science and technology. Royal society of chemistry.

Siddique, R., Chahal, N. (2011). Use of silicon and ferrosilicon industry by-products (silica fume) in cement paste and mortar. Resources, *Conservation and Recycling*, 55(8), 739-744.

Tanash, A. O., Muthusamy, K., Budiea, A. M., Fauzi, M. A., Jokhio, G., & Jose, R. (2023). A Review on the Utilization of Ceramic Tile Waste as Cement and Aggregates Replacement in Cement

Based Composite and a Bibliometric Assessment. *Cleaner Engineering and Technology*, 17, 100699. https://doi.org/10.1016/j.clet.2023.100699

Torkittikul, P., & Chaipanich, A. (2010). Utilization of ceramic waste as fine aggregate within Portland cement and fly ash concretes. *cement and concrete composites*, 32(6), 440-449.

Wang, H. (2009). A Study of The Effects of LCD Glass Sand on The Properties of Concrete. *Waste Management*, 29(1), 335-341. https://doi.org/10.1016/j.wasman.2008.03.005