PERFORMANCE OF WASTE GLASS POWDER CONCRETE SUBJECTED TO FIRE

Md. Khaliqul Bari*[1], Ismail Saifullah[2], Abdullah-Al-Taharat[3] and Md. Abir Hossan[4]

[1]*Undergraduate Student, Department of Civil Engineering, Khulna University of Engineering & Technology (KUET), Bangladesh, e-mail: bari.ce.kuet084@gmail.com*
[2]*Associate Professor, Department of Civil Engineering, Khulna University of Engineering & Technology (KUET), Bangladesh, e-mail: saifullah@ce.kuet.ac.bd*
[3]*Undergraduate Student, Department of Civil Engineering, Khulna University of Engineering & Technology (KUET), Bangladesh, e-mail: aongontaharat@gmail.com*
[4]*Undergraduate Student, Department of Civil Engineering, Khulna University of Engineering & Technology (KUET), Bangladesh, e-mail: abirhossan6686@gmail.com*

***Corresponding Author**

ABSTRACT

The implementation of recycling materials in concrete is increasing progressively because of the development of sustainable construction. A significant amount of waste glasses are generating all over the world. However, most of the waste glasses have been intentionally dumped into landfills. These waste glasses are not environmental friendly as glasses are not biodegradable, and, tremendous cost to individual corporations and municipalities to manage these waste. The increasing consciousness of glass recycling speeds up assessments on the utilization of waste glass powder in the concrete construction sector. This study mainly investigates the mechanical properties of concrete incorporating waste glass powder with partial substitution of binding material (cement) under when subjected to fire at elevated temperatures. This study also explores the influence of cooling approach on the glass powder concrete after burning in fire. Moreover, the density of the concrete both before and after burning in fire is also investigated. Total 108 cylindrical specimens were prepared with selected mixing ratio of 1:1.5:3 at a constant water cement ratio. Cement was substituted to some extent by waste glass powder at 10%, 15%, 20%, 25% and 30% by weight. After burning the specimens at elevated temperature, two seperate systems were followed for cooling the specimens (nature cooling in air and forced cooling in water) for the duration of 24 hours. The results show that 20% substitution of cement in concrete by using waste glass powder is found the feasible compressive and tensile strength compared to concrete containing without glass powder. It is also remarked that when concrete is subjected to fire, natural cooling approach provides better performance compared to forced cooling approach. However, there is no considerable reduction of concrete density observed due to substitution of cement by waste glass powder.

Keywords: *Waste glass powder, Fire, Compressive strength, Natural cooling, Forced cooling.*

1. INTRODUCTION

The generation of waste is increasing enormously because of the rapid growth of population and industry worldwide. Therefore, recycling of waste materials is becoming an acute concern all over the world (Taha & Nounu, 2009). Since the waste glass does not putrefy in the atmosphere, it becomes an unsustainable when it is disposed as landfills (Islam, Rahman, & Kazi, 2016). Shayan & Xu (2004) reported that the major industrial emissions of carbon dioxide (CO2) is because of the manufacture of cement which consequences to around 5% of worldwide man-made emissions. The implementation of recycling materials in concrete is increasing steadily because of the key goals of sustainable construction. Glasses are one kind of inert materials that could be recycled and used several cycles devoid of varying its chemical properties (Shayan & Xu, 2004). Jangid & Saoji (2014) reported that glass is a nebulous material containing high silica resulting to potential pozzolanic when particle magnitude is not as much of 75 µm.

The utilization of recycled glass in construction assist to save of energy. The increasing consciousness of glass recycling speeds up assessments on the utilization of waste glass with several patterns in numerous research fields. The amount of waste glass is gradually increased over the modern years by reason of an ever-growing usage of glass products. Nevertheless, most of the waste glasses have been get rid of into landfill spots which is disagreeable as glasses are not biodegradable, consequently less environmental friendly as well as tremendous cost to individual corporations and municipalities. There is an enormous prospective for utilizing waste glass in the sector of concrete construction. When waste glasses are recycled in manufacture of concrete members, the manufacture cost of concrete will be reduced (Topçu and Canbaz 2004; Srivastava et al. 2014).

Fire safety is crucial for the reinforced concrete structures. With the development of technology, constructions have been imparting additional competent facility and wellbeing for civilization in the former era (Durgun & Sevinç, 2019). During fire, the temperature can extent up to 1100˚C in building structures and steady up to 1350˚C in tunnel structures. When the temperature of the concrete conceeded 500˚C, the compressive strength of concrete typically declines 50% to 60%, and the concrete is measured as entirely damaged (Hager, 2013). Pozzolanic materials enhance the fire endurance of the concrete (Yüksel, Siddique, & Özkan, 2011).

Based on the mechanical properties of concrete as well as its alkali-silica reactivity, several researchers (such as Bažant et al. 2000; Shayan and Xu 2006; Schwarz and Neithalath 2008; Kataria 2010; De Castro and de Brito 2013) explored the suitability of waste glass powder as substitution of cement in concrete. Finely ground glass powders encompass substantial amount of silica (SiO_2) and exhibited very high pozzolanic activity (Shi et al. 2005; Carsana, Frassoni, & Bertolini, 2014; Kong et al. 2016; Omran et al. 2017; Khmiri et al. 2013). The finer the glass powder, the higher its pozzolanic reactivity. Pan, Tao, Murphy, & Wuhrer (2017) revealed that the exploitation of glass powder reduced the Ca(OH)2 amount along with the thermal conductivity. Besides, glass powder usage reduced the deficiency and spalling of the high-strength concrete under high temperatures (Ali, Dinkha, & Haido, 2017). Du and Tan (2015) investigated the mechanical and durability behavior of concrete integrating recycled glass powder and concluded that because of the pozzolanic reaction of glass powder, it can be utilized in concrete as substitution of cement to some extent and resulting to the reduction of carbon footprint. The exchange of Portland cement with ground glass powder also decreases the expansion because of the alkali-aggregate reactions (ASTM C1260). The integration of glass powder in mortars could considerably decrease the drying shrinkage of the glass mortars irrespective of its fineness (Lu et al. 2017). Therefore cement can be substituted by waste glass powder to some extent in concrete and participate to develop strength of concrete.

This study mainly focuses to the investigation of the mechanical properties of concrete incorporating waste glass powder with partial substitution of binding material (cement) under when subjected to fire at elevated temperatures. This study also explores the influence of cooling approach on the glass powder concrete after burning in fire. Moreover, the density of the concrete both before and after burning in fire is also highlighted.

2. METHODOLOGY

2.1 Materials and Methods

In this study Ordinary Portland cement, black stone chips, and Sylhet sand were used as raw materials. The physical properties of these construction materials were determined in accordance with relevant ASTM Standards as presented in Table 1. The disposed waste glasses were collected from locally available sources. Glass powder were prepared by grinding followed by several sequences till the passing of #200 sieve. Figure 1 depicts the entire procedures of preparation of glass powder.

Table 1: Physical properties of materials

Materials	Material Properties	Unit	Value
Coarse Aggregate	Specific Gravity	-	2.75
	Absorption	%	1.80
	Unit Weight	Kg/m^3	1517
Fine Aggregate	Specific Gravity	-	2.65
	Absorption	%	4.33
	Fineness Modulus	-	2.64
	Unit Weight	Kg/m^3	1600

a. Collection of waste glasses b. Crushed glasses c. Preparation of glass powder

Figure 1: Several strategies of making glass powder

2.2 Preparation of Specimens

The specimens was prepared with selected mixing ratio of 1:1.5:3. The water cement ratio for each specimen was 0.48. In this study cement was to some extent substituted with waste glass powder at different percentages such as 10%, 15%, 20%, 25% and 30% by weight. Total 108 cylindrical samples of 100 mm diameter and 200 mm height were cast. Among these specimens, 54 specimens were prepared for compressive strength test and 54 samples were prepared for splitting tensile strength test. Among 108 specimens, 36 specimens were prepared for each conditions like as control specimens, natural cooling and forced cooling. The samples were stored at water for the curing ages of 28 days. The workability of concrete for each batch mixing was also determined through slump test. The entire steps of preparation of cylindrical samples are presented in Figure 2.

a. Mixing Materials b. Workability Test c. Preparation of Specimens

Figure 2: Several steps for preparation of specimens

2.3 Testing of Specimens

2.3.1 Burning of Specimens

A fire chamber size of 550 x 450 x 400mm was prepared with electric coil heater for testing of concrete subjected to fire. Eight electric coil plates were used in the chamber surrounding walls. Each coil contains 2000 watt. The samples were stored in the chamber for one hour under fire conditions. The typical burning process of specimens is shown in Figure 3. The temperature was measured using thermocouple placed inside the chamber and found temperature ranging from 27^0C to 600^0C for the duration of one hour. The variation of temperature with regard to duration of burning of specimens is illustrated in Figure 4. After burning the specimens were cooled in two processes. One of them naturally cooled in air, other one forcedly cooled by water.

Figure 3: Burning of the specimens

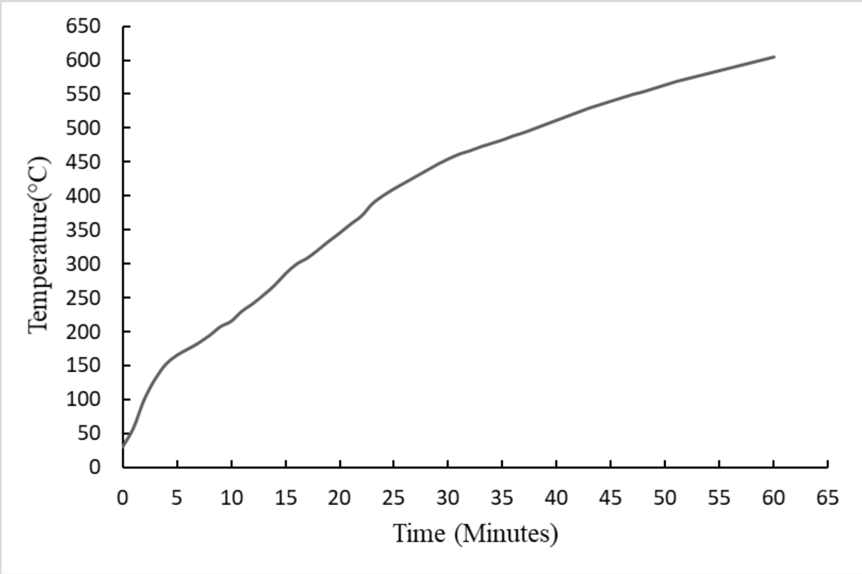

Figure 4: Variation of temperature with respect to Burning Period

2.3.2 Compressive Strength Test

The crushing strength of waste glass powder concrete at normal condition as well as after completion of the cooling process was conducted in accordance with ASTM C39 by using compression testing machine in the Engineering Materials Laboratory of KUET. The specimens were vertically setup in the machine. Figure 5 shows a typical test set-up for the determination of crushing strength of concrete. The load was executed gradually as per ASTM C39 standard while waiting for failure of the cylindrical samples. The compressive strength of concrete was obtained by divided the crushing load by cross sectional area of the specimens.

Figure 5: Typical test set-up for determination of crushing strength of concrete

2.3.3 Splitting Tensile Strength Test

The splitting tensile strength of waste glass powder concrete at both normal condition and after completion of the cooling process was carried out according to ASTM C496 by using compression testing machine. The samples were placed horizontally with the provision of bar along the long axis of the cylindrical specimen (shown in Figure 6). A typical test set-up for determination of splitting tensile strength of concrete is depicted in Figure 6.

Figure 6: Typical setup for spliting tensile strength determination

The load was applied gradually as per ASTM C496 standard till failure of the cylindrical samples. The splitting tensile strength of concrete was computed by using the Equation (1).

$$\sigma = \frac{2P}{\pi d l} \tag{1}$$

Where,
σ = splitting tensile strength, MPa
P = Largest applied load specified in the testing machine, kN
d = diameter of the sample, mm
l = length of the sample, mm

3. RESULTS AND DISCUSSIONS

3.1 Workability of Concrete

Workability means that the concrete easily flows and compacted without any segregation. Workability are remarkably influenced by aggregate property, water content and hydration of cement. The test results of workability at relevant percentage of cement replacement with glass powder is presented in Table 2. It has been found that waste glass powder increases the water demand that's why workability of the concrete containing waste glass powder gradually decrease with increase the percentage substitution of cement by waste glass powder in conjunction with a steady water cement ratio of 0.48.

Table 2: Determination of workability of glass powder concrete

Sample ID	Workability (mm)
0% GP	87
10% GP	81
15% GP	75
20% GP	72
25% GP	68
30% GP	65

3.2 Compressive strength of concrete

The compressive strength of concrete with the partial replacement of cement by waste glass powder have been investigated. At 28 days, the compressive strength generally decreases with glass powder containing around 15% as illustrated in Figure 7. However, no significant reduction of strength was detected for concrete incorporating 20% glass powder in comparison to concrete without glass powder (shown in Table 3). It can be occurred because of the pozzolanic reaction among cement hydration and glass powder products. This insignificant strength reduction was not detected for concrete where higher than 20% cement is substituted by glass powder. The pozzolanic reaction necessitates the hydration products, CH, whose extent is controlled through the cement content (Carsana, Frassoni, & Bertolini, 2014). Hence, there is a maximum boundary for the level of cement substitution, further than no additional pozzolanic reaction of glass powder can take place. In this condition, glass powder mainly behave as inert filler without being initiated. The results in this investigation point toward that glass powder exhibits noticeable pozzolanic reaction when the substitution amount of cement is approximately 20%. Du and Tan (2014) reported that the pozzolanic reaction enhances the pore structure in the bulk cement paste in addition to the interfacial transition zone among cement paste and coarse aggregates. This interfacial transition zone dominates the mechanical properties of concrete because of its more porousness in comparison with the bulk paste. Du and Tan (2014) also stated that CH content is also comparatively greater at interfacial transition zone which facilitates the pozzolanic reaction of waste glass powder. The improved microstructure at interfacial transition zone has participated to the compressive strength of concrete with approximately 20% glass powder content.

From Table 3 it can be observed that concrete compressive strength decreases significantly when subjected to fire at elevated temperature. After burning the specimens in fire, cooling process was carried out for the duration of 24 hours in both natural cooling and forced cooling approach. It is observed that the compressive strength of concrete at natural cooling approach provides better performnce compared to forced cooling approach as depicted in Figure 7 and Table 3.

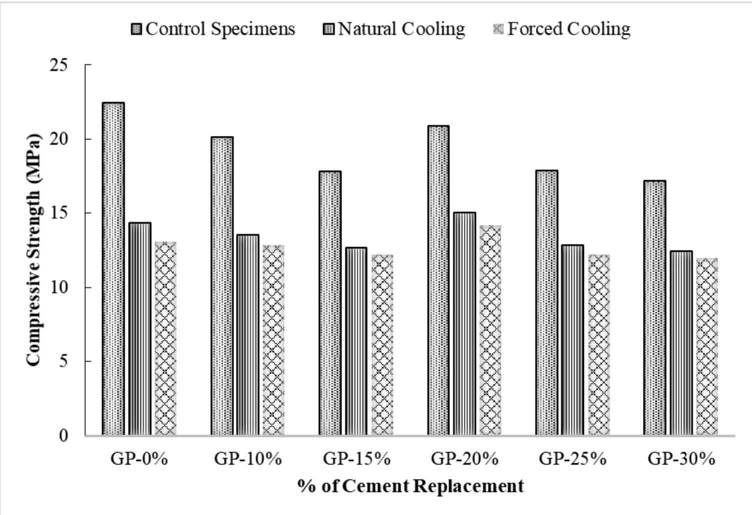

Figure 7: Assessment of compressive strength of glass powder concrete at different conditions.

Table 3: Compressive strength of concrete at 28 days

Sample ID	Control specimens (MPa)	Strength reduction in regard to control samples (%)	Natural cooling (MPa)	Strength reduction in regard to control samples (%)	Forced cooling (MPa)	Strength reduction in regard to control samples (%)
0% GP	22.43	--	14.32	36.16	13.05	41.82
10% GP	20.15	10.16	13.53	32.85	12.82	36.38
15% GP	17.82	20.55	12.66	28.96	12.22	31.43
20% GP	20.90	6.82	15.05	28.02	14.16	32.25
25% GP	17.85	20.42	12.87	27.90	12.21	31.60
30% GP	17.18	23.41	12.44	27.60	11.98	30.27

3.3 Tensile strength of concrete

In this study the tensile strength of concrete containing waste glass powder as partial substitution of cement have also been investigated. From Figure 8 it can be stated that the splitting tensile strength reduces with the increase of the incorporating glass powder of approximately 15%. However, there is no significant reduction of tensile strength witnessed for concrete encompassing 20% glass powder compared to control specimens as presented in Table 4. It can be occurred because of the pozzolanic reaction among cement hydration and glass powder products. Nevertheless, the reduction of tensile strength of concrete increases when more than 20% cement is replaced by waste glass powder. Hence, there is an upper limit boundary for the level of cement substitution, further than no additional pozzolanic reaction of glass powder can take place. The illustrations of the reason are already mentioned in section 3.2. Therefore, the results of this study specify that glass powder exhibits noticeable pozzolanic reaction when the replacement level of cement is approximately 20%.

From Table 4 it can be specified that the splitting tensile strength of concrete declines considerably under fire at elevated temperature. After burning the specimens in fire, similar cooling process suhc as natural cooling and forced cooling was performed for the duration of 24 hours. It has also been remarked that the spliiting tensile strength of concrete at natural cooling approach provides better performnce in comparison to forced cooling approach as depicted in Figure 8 and Table 4.

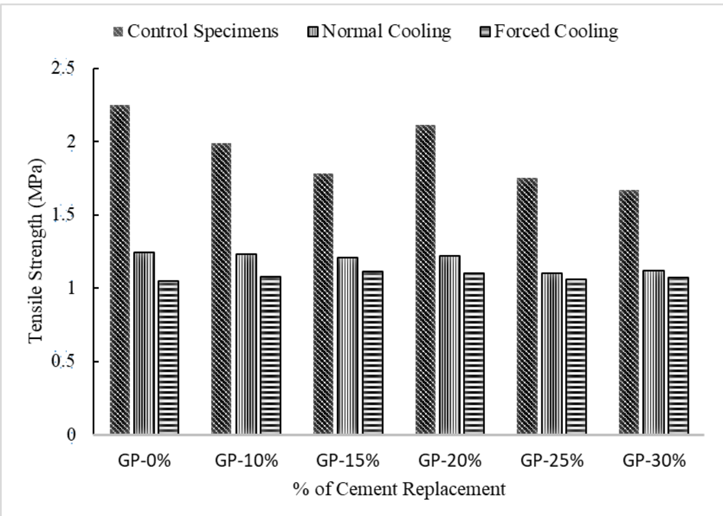

Figure 8: Assessment of spliting tensile strength of glass powder concrete at different conditions.

Table 4: Spliting Tensile strength of concrete at 28 days

Sample ID	Control specimens (MPa)	Strength reduction in regard to control samples (%)	Natural Cooling (MPa)	Strength reduction in regard to control samples (%)	Forced Cooling (MPa)	Strength reduction in regard to control samples (%)
0% GP	2.25	--	1.24	44.89	1.05	53.33
10% GP	1.99	11.56	1.23	38.19	1.08	45.73
15% GP	1.78	20.89	1.21	32.02	1.11	37.64
20% GP	2.11	6.22	1.22	42.18	1.10	47.87
25% GP	1.75	22.22	1.10	37.14	1.06	39.43
30% GP	1.67	25.78	1.12	32.93	1.07	35.91

3.4 Density

The density of concrete at non burnt condtions was measured at the ages of 28 days. It has been remarked that there is no significant reduction of concrete density due to replacement of cement by waste glass powder as exhibited in Table 5. The density of glass powder concrete slightly decreases with the increases of the percentage replacement of cement by waste glass powder. At non burnt condition, when the concrete incorporating no glass powder it possesses the density of 2559 kg/m^3 whereas the density becomes 2514 kg/m^3 for 30% substitution of cement by waste glass powder. After burning in fire, the specimens were cooled by naturally in air and forcedly by water, and measured the density of concrete at both conditions. It was found that at fire conditions there is no significant variation of concrete density compared to concrete at non burnt condtion. However, the density of concrete at natural cooling approach shows slightly lower density than forced cooling approach.

Table 5: Density of concrete at 28 days

Sample ID	Density(Kg/m^3)		
	Control Specimens	Natural Cooling	Forced Cooling
0% GP	2559	2370	2537
10% GP	2543	2349	2528
15% GP	2530	2316	2513
20% GP	2527	2337	2506
25% GP	2523	2332	2499
30% GP	2514	2335	2492

4. SUMMARY AND CONCLUSIONS

This study mainly investigates the mechanical properties of concrete incorporating waste glass powder with partial substitution of binding material (cement) under when subjected to fire at elevated temperatures. This study also explores the influence of cooling approach on the glass powder concrete after burning in fire. Based on the experimental studies, the comprehending conclusions have been achieved:

- The workability of the waste glass powder concrete gradually decreases with the increase of the partial substitution of cement by waste glass powder at a steady water cement ratio.
- There is no substantial reduction of both compressive and tensile strength observed for concrete incorporating 20% glass powder as substitution of cement in comparison to concrete without glass powder. This study designate that glass powder exhibits recognizable pozzolanic reaction when the replacement level of cement is approximately 20%. Therefore, it is suggested that approximately 20% cement can be substituted by using waste glass powder to make viable structural concrete resulting to the lower amount of cement consumption in

construction, and hence proving environmentally friendly as well as economically beneficially construction.

- Based on the compressive and splitting tensile strength of concrete after burning in fire, it can be stated that natural cooling approach provides better performnce compared to forced cooling approach.
- The density of glass powder concrete slightly declines with the increases of the percentage replacement of cement by waste glass powder. However, there is no considerable reduction of concrete density observed due to partial substitution of cement by waste glass powder.

ACKNOWLEDGEMENTS

We want to express our acknowledgements to all of the Laboratory employees of Engineering Materials, Department of Civil Engineering, Khulna University of Engineering & Technology for their valuable cooperation during the course of the research period.

REFERENCES

Ali, M. H., Dinkha, Y. Z., & Haido, J. H. (2017). Mechanical properties and spalling at elevated temperature of high performance concrete made with reactive and waste inert powders. Engineering Science and Technology, an International Journal, 20(2), 536-541.

ASTM C39. 2018. Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens. Annual Book of ASTM Standards, Volume 04.02.

ASTM C496. 2017. Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens. Annual Book of ASTM Standards, Volume 04.02.

ASTM C1260. 2014. "Standard Test Method for Potential Alkali Reactivity of Aggregates (Mortar-Bar Method)." Annual Book of ASTM Standards, Volume 04.02.

Bažant, Z. P., Zi, G., & Meyer, C. (2000). Fracture mechanics of ASR in concretes with waste glass particles of different sizes. Journal of engineering mechanics, 126(3), 226-232.

Carsana, M., Frassoni, M., & Bertolini, L. (2014). Comparison of ground waste glass with other supplementary cementitious materials. Cement and Concrete Composites, 45, 39-45.

De Castro, S., & de Brito, J. (2013). Evaluation of the durability of concrete made with crushed glass aggregates. Journal of Cleaner Production, 41, 7-14.

Du, H., & Tan, K. H. (2015). Durability performance of concrete with glass powder as supplementary cementitious material. XIII International Conference on Durability of Building Materials and Components - XIII DBMC, Sao Paulo, Brazil, 928-935.

Du, H., & Tan, K. H. (2014). Waste glass powder as cement replacement in concrete. Journal of Advanced Concrete Technology, 12(11), 468-477.

Durgun, M. Y., & Sevinç, A. H. (2019). High temperature resistance of concretes with GGBFS, waste glass powder, and colemanite ore wastes after different cooling conditions. Construction and Building Materials, 196, 66-81.

Hager, I. (2013). Behaviour of cement concrete at high temperature. Bulletin of the Polish Academy of Sciences: Technical Sciences, 61(1), 145-154.

Kataria, A., Kumar, M. G., & Goyal, S. G. (2010). Studies on Mechanical Properties of Concrete Containing Waste Glass Powder and Post Consumer Waste Plastic (Doctoral dissertation). Thapar Univers, Patiala.

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.

Kong, Y., Wang, P., Liu, S., Zhao, G., & Peng, Y. (2016). SEM analysis of the interfacial transition zone between cement-glass powder paste and aggregate of mortar under microwave curing. Materials, 9(9), 733.

Islam, G. S., Rahman, M. H., & Kazi, N. (2017). Waste glass powder as partial replacement of cement for sustainable concrete practice. International Journal of Sustainable Built Environment, 6(1), 37-44.

Jangid, J. B., & Saoji, A. C. (2014). Experimental investigation of waste glass powder as the partial replacement of cement in concrete production. In International Conference on Advances in Engineering & Technology (pp. 55-60).

Lu, J. X., Zhan, B. J., Duan, Z. H., & Poon, C. S. (2017). Using glass powder to improve the durability of architectural mortar prepared with glass aggregates. Materials & Design, 135, 102-111.

Omran, A. F., Etienne, D., Harbec, D., & Tagnit-Hamou, A. (2017). Long-term performance of glass-powder concrete in large-scale field applications. Construction and Building Materials, 135, 43-58.

Pan, Z., Tao, Z., Murphy, T., & Wuhrer, R. (2017). High temperature performance of mortars containing fine glass powders. Journal of Cleaner Production, 162, 16-26.

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.

Shayan, A., & Xu, A. (2006). Performance of glass powder as a pozzolanic material in concrete: A field trial on concrete slabs. Cement and concrete research, 36(3), 457-468.

Shayan, A., & Xu, A. (2004). Value-added utilisation of waste glass in concrete. Cement and concrete research, 34(1), 81-89.

Shi, C., Wu, Y., Riefler, C., & Wang, H. (2005). Characteristics and pozzolanic reactivity of glass powders. Cement and Concrete Research, 35(5), 987-993.

Srivastava, V., Gautam, S. P., Agarwal, V. C., & Mehta, P. K. (2014). Glass waste as coarse aggregate in concrete. Journal of Environmental Nanotechnology, 3(1), 67-71.

Taha, B., & Nounu, G. (2009). Utilizing waste recycled glass as sand/cement replacement in concrete. Journal of materials in civil engineering, 21(12), 709-721.

Topcu, I. B., & Canbaz, M. (2004). Properties of concrete containing waste glass. Cement and concrete research, 34(2), 267-274.

Yüksel, İ., Siddique, R., & Özkan, Ö. (2011). Influence of high temperature on the properties of concretes made with industrial by-products as fine aggregate replacement. Construction and building materials, 25(2), 967-972.