Nature Environment and Pollution Technology
An International Quarterly Scientific Journal
p-ISSN: 0972-6268
(Print copies up to 2016)
e-ISSN: 2395-3454
Vol. 22 No. 1 pp. 517-522 2023
Original Research Paper
https://doi.org/10.46488/NEPT.2023.v22i01.051
Open Access Journal

Use of Ground Glass Waste as Aggregate Filler in Concrete

A. S. Pasana*† , M. E. Loretero* and M. B. Giduquio*
*School of Engineering, University of San Carlos, Talamban Campus, Cebu City 6000, Philippines
†Corresponding author: A .S. Pasana; aspasana16@gmail.com

Nat. Env. & Poll. Tech.
Website: www.neptjournal.com

Received: 27-05-2022
Revised: 19-07-2022
Accepted: 21-07-2022

Key Words:
Waste glass
Concrete
Mechanical properties
Densified concrete mix

ABSTRACT

The disposal of the huge volume of glass waste is one of the significant environmental issues that need to be addressed. One of the efficient ways to solve this problem is to incorporate ground glass waste in concrete mixtures. However, its inherent surface smoothness and microcracks within the glass particle harm the hardened properties of concrete. Minimizing the particle size and controlling the amount of cement in the mixture can reduce the adverse effect of using glass in concrete. This study utilized ground glass waste (850 μm) as aggregate filler in a concrete mix. More specifically, this study investigated the effect of paste volume (Vp) on the properties of fresh and hardened concrete with ground glass waste as aggregate filler. Based on the test results, ground glass waste as aggregate filler negatively affects the workability of fresh concrete, but increasing the amount of paste can mitigate it. Vp values in terms of void volume (Vv) in the aggregates of 1.6Vv and 1.8Vv achieved satisfactory consistency of fresh concrete. In addition, the concrete compressive strength increased when increasing Vp. The test results have shown that ground glass waste has the potential to be utilized as aggregate filler in concrete mixtures.

INTRODUCTION

In the coming ten years, it is anticipated that glass manufacturing will increase steadily worldwide. Construction industries already accounted for $81.9 billion in 2015 and forecast a compound annual growth rate of 7.6% from 2016 to 2022 (Precient & Strategic Intelligence 2021). Consequently, this increasing demand for glass products also entails a growing volume of generated glass waste. Though used glass can be utilized in producing a new glass, the recycling process is limited by the production cost and impurities or mixed colors (Shi & Zheng 2007). For example, in the Philippines, only around 48.5% of post-consumer waste glass bottles were reutilized (National Solid Waste Commission 2018). Since glass cannot be decomposed or incinerated, a considerable volume of cullet occupies high-valued land space, which may potentially cause environmental issues.

The hardness and nonbiodegradability properties of glass make it a suitable aggregate substitute for concrete (Rashad 2014, Jamshidi et al. 2016, Gahoi & Kansal 2016, Afshinnia & Rangaraju 2015). In addition, recycling glass waste as an aggregate substitute in concrete may be one of the most practical options because it can be used in large quantities with low-quality requirements and has a potentially broader scope of application (Shi & Zheng 2007).

Despite the promising application of glass waste in concrete production, the proportion of glass waste incorporated in concrete should be appropriately considered. Based on Park et al. (2004), concrete compaction in concrete specimens was degraded as the glass waste amount was increased, resulting in a decreased slump, increased air content, and consequently reduced concrete density (Topcu & Canbaz 2004). This effect was mainly attributed to the shape irregularity of waste glass with particle size generally larger than 600 μm. In addition, concrete compressive strength reduces as the quantity of waste glass increases because adherence between waste glass and cement paste cannot be fully achieved (Topçu & Canbaz 2004) due to the inherent smooth surface of glass particles. Another concern about using glass waste as an aggregate substitute is the potential alkali-silica reaction (ASR), which may result in undesirable expansion and cracking in concrete (Khan & Sarker 2019). However, some studies (Zhu et al. 2009, Lee et al. 2011) have shown that ASR expansion decreased with decreasing glass particle size. Maraghechi et al. (2012) explained that ASR occurred within interior cracks of glass particles originating from glass crushing and not on the glass-paste interface. Based on the scanning electron microscope (SEM) images, ASR was only observed between cracks larger than 2 μm in ground glass waste with particle sizes larger than 1.18 mm. In addition, controlling cement type and content and aggregates' size can mitigate ASR-related issues (Penacho et al. 2014).

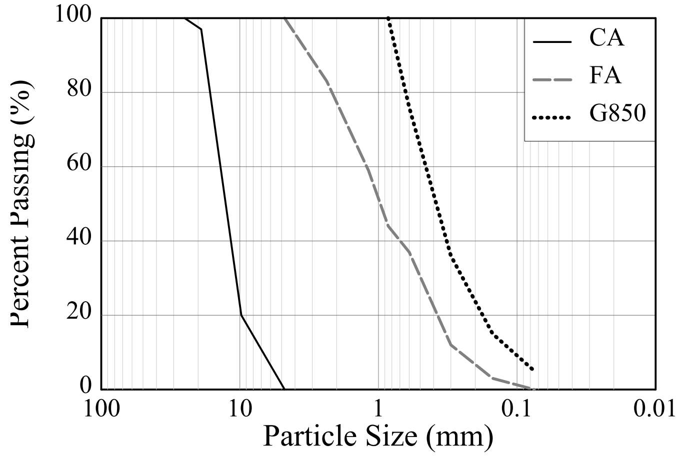

Fig. 1. Particle size distribution.

The particle packing method introduced by Tasi et al. (2006) essentially controls the amount of cement needed in a concrete mix. Successively filling voids within aggregates of coarser particle size with relatively smaller ones effectively reduces the void to be filled by the cement paste, leading to an increase in mixture density. Workability is controlled by adjusting paste volume or applying a superplasticizer.

Most studies related to particle packing utilize fly ash as a micro filler. This study evaluates the applicability of glass waste as aggregate micro filler in normal-strength concrete. It mainly focuses on the effect of paste volume on the workability and compressive strength of concrete with ground glass waste.

MATERIALS AND METHODS

Materials and Characterization

The glass waste used in this study was sourced from a local jalousie window fabricator. The glass waste was washed, air-dried, and ground using a hammer mill. The ground glass waste was then sieved using an 850-μm sieve. Glass particles passing an 850-μm sieve, referred to as G850, were used. The particle size was smaller than 1.18 mm to avoid ASR-related issues (Maraghechi et al. 2012). G850 had a specific gravity of 2.50 and a fineness modulus of 1.73. The particle size distribution of G850 is presented in Fig. 1.

The coarse aggregates (CA) used in this study were crushed river gravel with a specific gravity of 2.40, water absorption of 2.31%, and a fineness modulus of 6.80. Fine aggregates (FA) were river sand with a specific gravity of 2.46, water absorption of 2.31%, and a fineness modulus of 3.00. Particle size distributions of CA and FA are also presented in Fig. 1. The cement used was a Type-1 Portland with a specific gravity of 3.11.

Aggregate Proportioning

The proportion of aggregates was obtained based on the maximum particle packing density per Tasi et al. (2006). Coarse aggregates were increasingly blended with fine aggregates, and corresponding dry-rodded densities of the blends with different fine-to-coarse aggregate ratios were determined per ASTM International C29/C29M-17 (2017). This process was continued until an apparent drop in density was obtained. The fine-to-coarse aggregate ratio corresponding to the maximum dry-rodded density was then obtained using quadratic regression and was used as a constant fine-to-coarse aggregate ratio. Then, the fine and coarse aggregates were increasingly blended with G850. Finally, the glass-fine-coarse aggregate proportion corresponding to the maximum dry-rodded density of the blend was obtained using the same process mentioned above. The final aggregate proportion by mass was 45.5% coarse aggregate, 47.6% fine aggregate, and 6.9% G850, with a dry-rodded density of 1874.1 $kg.m^{-3}$ of the mixture.

Concrete Mix Design

Ideally, the paste volume (V_p) - or the amount of cement paste - needed is equivalent to the volume of void (V_v) in the aggregates. However, in the actual case, V_p is always higher than V_v to account for the additional paste necessary for lubrication to facilitate better consistency of the concrete mix.

In this study, the proportion of aggregates was based on the maximum dry-rodded density obtained in the particle packing procedure described above and common to all specimens. A constant water-to-cement ratio (w/c) of 0.54 by mass was used to proportion the cement paste. This w/c ratio was based on the recommended value per ACI Committee 211 (1991) for non-air-entrained concrete with specified concrete strength of 30 MPa. The main parameter

Table 1: Mix proportions per cubic meter of concrete.

Specimen	CA [kg]	FA [kg]	G850 [kg]	Cement [kg]	Water [kg]
G-1.2Vv	815	853	124	307	166
G-1.4Vv	780	817	119	343	185
G-1.6Vv	749	784	114	376	203
G-1.8Vv	720	753	110	406	219
G-2.0Vv	693	725	106	435	235
C-1.6Vv	803	840	0	376	203

of this study was the V_p in terms of the V_v of the aggregates. Initially, the study considered five V_p values ranging from 1.2Vv to 2.0Vv. However, the concrete mix with 1.2V_v was relatively drier and not workable, and concrete with 2.0V_v was observed to have severe segregation during the trial mix. Hence, only three V_p values (1.4V_v, 1.6V_v, and 1.8V_v) were used in this study. The mix proportions of the specimens are summarized in Table 1 based on a cubic meter of concrete mix. In Table 1, the samples are labeled as follows: the first alphabetic character refers to the presence of G850 in the mixture (G for with G850 and C for conventional mix without G850); the following symbols after the hyphen correspond to the paste volume. Another concrete mix, C-1.6Vv, without G850, was added as a conventional mix, and its amount of cement paste was similar to G-1.6Vv. The FA-CA ratio was constant in all concrete mixtures, but the total mass of aggregates (CA+FA) in C-1.6Vv was similar to that in G-1.6Vv (CA+FA+G850). It should be noted that the paste volume in C-1.6Vv did not necessarily correspond to the 1.6Vv, but rather, it was the intention of this study to maintain the amount of paste in the concrete mix in both specimens for direct comparison. The paste volume of C-1.6Vv was around 1.42Vv, lower than that of G-1.6Vv because of the larger Vv compared to concrete mixtures with G850.

Preparation and Testing of Samples

One batch of the concrete mix was used for each mix proportion. Test specimens were prepared following ASTM International C192/C192M-19 (2019). The concrete constituent materials were blended using a conventional 1-bagger mixer. The slump of the fresh concrete was obtained as per ASTM International C143/C143M-15 (2015). For each concrete mix, nine 100 mm x 200 mm concrete cylinder samples were cast per ASTM International C192/192M-19 (2019). These nine concrete cylinder samples included three sets of 3 specimens for 7-, 28- and 56-day strengths. The mold's opening was covered with plastic wrap to minimize evaporation loss. After 24 h, the concrete specimens were demolded and cured in potable water at room temperature. The samples were tested for compressive strength at 7, 28, and 56 days.

RESULTS AND DISCUSSION

Workability

Specimen G-1.2Vv was observed to be relatively drier and unworkable. A closer look at the aggregate particles revealed that a significant portion remained uncoated with paste. The amount of paste in specimen G-1.2Vv was essentially not sufficient. The slump was not determined for this concrete mix and was not cast for the compression test. At a paste volume of 1.4Vv, the paste amount seemed sufficient to coat the aggregates but not enough to provide lubrication between particles in specimen G-1.4Vv. The concrete was essentially very stiff and had a slump of zero. Aggregates in specimen G-1.6Vv were essentially coated with cement, and the amount of cement paste seemed sufficient to provide better consistency in the concrete mix. It had a slump of 30 mm, which was well within the desired value for structural application. When increasing the paste volume of 1.8Vv, the slump value of specimen G-1.8Vv increased to 70 mm without visible segregation of aggregates. However, the concrete mix showed significant segregation and bleeding in specimen G-2.0Vv (with a paste volume of 2.0Vv). During the slump test, the fresh concrete collapsed. Apparent segregation of aggregate particles was observed, and the cement paste flowed outward freely. No concrete cylinder samples were prepared for this concrete mix. Based on the test results, the slump of fresh concrete with G850 increased as the paste volume increased. However, the amount of paste volume should be limited to avoid bleeding and segregation. These observations were similar to the findings of Ling and Kwan (2015) that, beyond a certain point, increasing paste volume in concrete decreased the dimensional stability of concrete.

Specimen C-1.6Vv was relatively easier to mix compared to specimen G-1.6Vv. Qualitatively, with a slump of 40 mm, the consistency of the fresh concrete of specimen C-1.6Vv was relatively better than that of specimen G-1.6Vv. It should be noted that in terms of Vv, the paste volume in specimen C-1.6Vv was only around 1.42Vv. With similar Vp in terms of Vv, C-1.6Vv was essentially more workable at a fresh concrete state, which indicated that the addition of glass negatively affected the consistency of concrete. This adverse impact might be attributed to the irregularity of glass particles which could increase frictional resistance between particles due to the interlocking of particles (Jamshidi et al. 2016). In addition, the increased surface area of aggregates due to other smaller particles in G850 had also increased the demand for the paste to bind the particles together and for lubrication.

The amount of paste in the concrete mix directly influenced the workability of the fresh concrete. It should be noted that the idea of maximizing the packing density of aggregates will result in the reduction of the void and, consequently, the paste required to coat the aggregates. However, fresh concrete should be workable enough to facilitate better compaction, which can directly affect hardened concrete properties. Based on the concrete mixtures with G850 in this study, paste volume should be within 1.6Vv and 1.8Vv to ensure satisfactory fresh concrete consistency and avoid segregation and bleeding.

Compressive Strength

The compressive strengths of the specimens are summarized in Table 2 and presented in Fig. 2. The 7-day strengths of the specimens had at least 21 MPa, roughly 70% of their respective 28-day strengths, and increased gradually in the later age. Among the specimens with G850, G-1.4Vv had the lowest strength. This result might be attributed to the stiff fresh concrete characteristics, which led to poor compaction in preparing concrete cylinder specimens. Concrete compressive strength increased as the paste volume increased. This strength increase could be associated with the better compaction of fresh concrete mixtures with higher paste volume.

Compared to specimen C-1.6Vv with conventional concrete mix, specimen G-1.4Vv with similar Vp in Vv had slightly lower strength. However, similar strengths were observed in both specimens, C-1.6Vv and G-1.6Vv, which have similar paste amounts by mass. Though not significant, G-1.8Vv had the highest compressive strength among the specimens considered in this study. This result implies that concrete specimens would have comparable strength provided the amount of cement paste is sufficient to be workable and the water-to-cement ratio is similar.

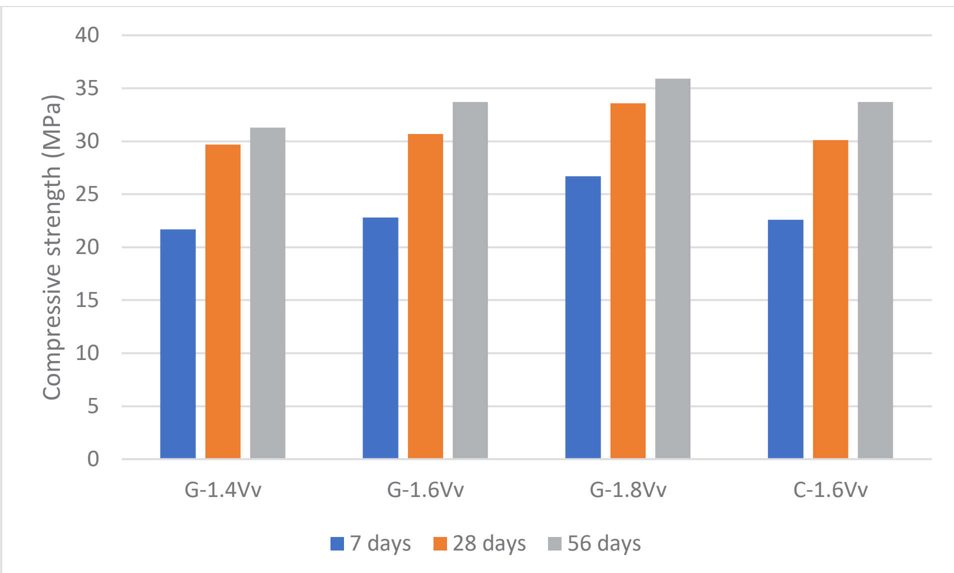

Fig. 2. The compressive strength of the glass-filled concretes at various paste volumes.

Table 2: Concrete compressive strength and cement efficiency index.

Specimen	Compressive Strength [MPa]			Cement Strength Efficiency [$kPa.kg^{-1}$]		
	7-day	28-day	56-day	7-day	28-day	56-day
G-1.4Vv	21.7	29.7	31.3	63.3	86.9	91.5
G-1.6Vv	22.8	30.7	33.7	60.9	81.7	89.8
G-1.8Vv	26.7	33.6	35.9	65.8	82.7	88.4
C-1.6Vv	22.6	30.1	33.7	60.3	80.1	89.9

The incorporation of G850 in the concrete mixture provides economic and environmental incentives. Furthermore, considering that all specimens had comparable strengths compared to C-1.6Vv, G850 could be used as aggregate filler in the formulation of structural concrete. Based on the concrete mix proportions considered in this study, G850 can potentially replace about 7 percent of the aggregates by mass.

Cement Strength Efficiency

The strength efficiency of cement on all the concretes is summarized in Table 2 and presented in Fig. 3. The values denote the yielded compressive strength per one-kilogram cement. Since this adhesive powder is the most expensive concrete-making-materials, these data would serve as a cost-benefit analysis. Likewise, the data assess the carbon footprint, wherein the more efficient the powder, the lesser carbon dioxide generated. As observed, a clear relationship between the values and PV prevails at a later period. Specifically, at 56 days, G-1.4Vp (with the least PV) achieved a higher value by 1.9% than G-1.6Vp and 3.6% than G-1.8Vp. Hence, the less paste, the more efficient. Also, G-1.6Vp (with filler) had higher efficiency than its control (C-1.6Vp) by 1.0% at seven days and 1.9% at 28 days, but both were equivalent at 56 days. This finding demonstrates that G850 did not reduce the strength efficiency of cement and, therefore, can lessen the required dosage of sand, gravel, and cement.

CONCLUSION

This paper explored the possible use of 850-μm glass as an aggregate supplement. The investigation centered on the optimum packing density of the glass-sand-gravel mixture and the concrete's workability and compressive strength at various water-cement paste volumes. Based on the findings, the following conclusions were drawn:

- In packing density, the optimum ratios by weight were 51.1:48.9 for sand-gravel and 6.9:47.6:45.5 for glass-sand-gravel, indicating that an optimum mixture contains more fine particles. The glass lowered the voids volume by around 6.9% and increased the density by about 1.77%. The voids reduction corresponds to a saving of water-cement paste.
- In concrete mix design, the volumetric paste increment by 0.2Vp relatively reduced the aggregates content by about 3.95% or 62 kg per one-cubic-meter concrete. The incorporation of glass saves around 6.7% of sand and gravel at a fixed amount of paste.
- The workability improved by increasing paste volume to 1.8Vp: zero-slump for 1.4Vp, 30 mm for 1.6Vp, and 70 mm for 1.8Vp. The 1.2Vp was insufficient to coat the aggregates, while 2.0Vp resulted in slump failure. However, the workability was reduced with the incorporation of glass.
- In compression, all the glass concretes reached the required design strength (30 MPa), and the fortification improved as paste volume was increased up to 1.8Vp. This finding indicates the suitability of glass aggregate at various paste volumes.
- The compressive-strength efficiency of cement negatively correlates with paste volume: the lesser the

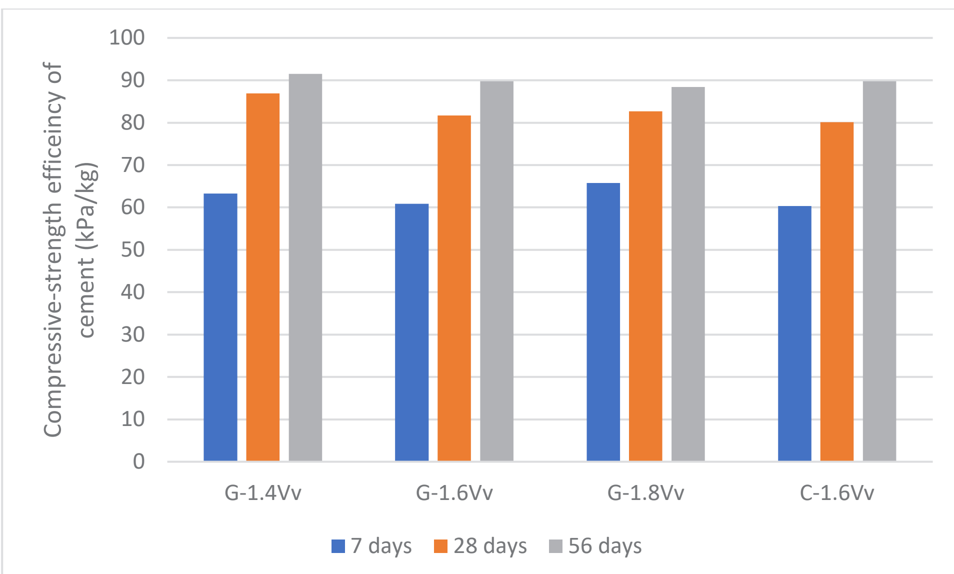

Fig. 3: The compressive-strength efficiency of cement at various paste volumes.

paste, the more efficient the cement. This efficiency is not negatively affected by G850, which supports the suitability of glass waste in concrete production.

Overall, recycling can reduce the amount of sand, gravel, and cement. This finding can promote glass utilization in concrete production, generating economic and environmental incentives in both glass and concrete contexts. In particular, it can solve the waste disposal crisis of the glass industry, particularly the jalousie window enterprises; likewise, it can free the existing dumpsite for other uses.

ACKNOWLEDGEMENT

This research was supported by the Commission on Higher Education, the University of San Carlos, and the Visayas State University.

REFERENCES:

ACI Committee 211. 1991. Standard Practice for Selecting Proportions for Normal, Heavyweight, and Mass Concrete. American Concrete Institute, Michigan, US.

ASTM International C29/C29M-17. 2017. Standard Test Method for Bulk Density ("Unit Weight") and Voids in Aggregate. ASTM, West Conshohocken.

ASTM International C143/C143M-15. 2015. Standard test method for the slump of hydraulic-cement concrete. Annual Book of ASTM Standards. ASTM, West Conshohocken

ASTM International C192/C192M-19 2019. Making and Curing Concrete Test Specimens in the Laboratory. ASTM, West Conshohocken.

Afshinnia, K. and Rangaraju, P.R. 2015. Influence of fineness of ground recycled glass on mitigation of alkali-silica reaction in mortars. Constr. Build, Mater., 81: 257-267.

Gahoi, K. and Kansal, R. 2016. Effect of waste glass powder on properties of concrete: A literature review. Int. J. Sci. Res., 11: 7064

Jamshidi, A., Kurumisawa, K., Nawa, T. and Igarashi, T. 2016. Performance of pavements incorporating waste glass: The current state of the art. Renew. Sustain. Energy Rev., 64: 211-236.

Khan, M.N.N. and Sarker, P.K. 2019. Alkali silica reaction of waste glass aggregate in alkali-activated fly ash and GGBFS mortars. Mater. Struct., 52(5): 93.

Lee, G., Ling, T.C., Wong, Y.L. and Poon, C.S. 2011. Effects of crushed glass cullet sizes, casting methods and pozzolanic materials on ASR of concrete blocks. Construction and Building Materials, 25(5): 2611-2618.

Ling, S.K. and Kwan, A.K.H. 2015. Adding ground sand to decrease paste volume, increase cohesiveness and improve passing ability of SCC. Constr. Build. Mater., 84: 46-53.

Maraghechi, H., Shafaatian, S.M.H., Fischer, G. and Rajabipour, F. 2012. The role of residual cracks on alkali-silica reactivity of recycled glass aggregates. Cem. Concr. Comp., 34(1): 41-47.

National Solid Waste Commission. 2018. Final Report, Volume 1. Retrieved from http://nswmc.emb.gov.ph/wp-content/uploads/2018/03/Final-Report-Volume-I.pdf

Park, S.B., Lee, B.C. and Kim, J.H. 2004. Studies on mechanical properties of concrete containing waste glass aggregate. Cem. Concr. Res., 34(12): 2181-2189.

Penacho, P., Brito, J. and Rosário Veiga, M. 2014. Physico-mechanical and performance characterization of mortars incorporating fine glass waste aggregate. Cem. Concr. Comp., 50: 47-59.

Precient & Strategic Intelligence. 2021. Global Construction Glass Market Size, Share, Development, Growth, and Demand Forecast to 2022 – Industry Insights by Type (Apparel Construction Glass and Non-Apparel Construction Glass) by Application (Industrial Protective Clothing, Defense and Firefighting Services, Transportation, Others). Retrieved from https://www.psmarketresearch.com/market-analysis/construction-glass-market

Rashad, A.M. 2014. Recycled waste glass as fine aggregate replacement in cementitious materials based on Portland cement. Constr. Build. Mater., 72: 340-357.

Shi, C. and Zheng, K. 2007. A review on the use of waste glasses in the production of cement and concrete. Resour. Conserv. Recycl., 52(2): 234-247.

Tasi, C.T., Li, L.S. and Hwang, C.L. 2006. The effect of aggregate gradation on engineering properties of high performance concrete. J. ASTM Int., 3(3): 13410.

Topçu, İ.B. and Canbaz, M. 2004. Properties of concrete containing waste glass. Cem. Concr. Research, 34(2): 267-274.

Zhu, H., Chen, W., Zhou, W. and Byars, E.A. 2009. Expansion behaviour of glass aggregates in different testing for alkali-silica reactivity. Mater. Struct., 42(4): 485-494.