IOP Conference Series: Earth and Environmental Science

PAPER • **OPEN ACCESS**

Towards greener concrete: a comprehensive review of waste glass powder as a partial fine aggregate substitute

To cite this article: S J S Hakim *et al* 2024 *IOP Conf. Ser.: Earth Environ. Sci.* **1347** 012072

Towards greener concrete: a comprehensive review of waste glass powder as a partial fine aggregate substitute

S J S Hakim[1*], A M Mhaya[1], S N Mokhatar[1], A F Kamarudin[1], Y G Tong[1] and T N T Chik[1]

[1] Department of Civil Engineering, Faculty of Civil Engineering and Built Environment, University Tun Hussein Onn Malaysia (UTHM), Johor, Malaysia
*Corresponding author: seyedhakim@uthm.edu.my

Abstract. Concrete typically emerges as the superior choice in terms of strength, adaptability, longevity, noise reduction, energy efficiency, and it additionally possesses the advantage of being fully recyclable. The excessive consumption of natural resources such as sand in traditional concrete production poses environmental concerns and makes concrete production as a significant contributor to greenhouse gas emissions. By using waste glass powder as a partial substitute for fine aggregate, the study explores the potential to lower the carbon footprint of concrete, to reduce the reliance on virgin materials, minimize waste generation, and promote sustainable practices in the construction sector and finally contributing to climate change mitigation and environmental stewardship. Also, it can offer cost savings, as waste glass is often readily available at low cost, reducing the dependence on expensive virgin materials. This article assesses the workability, durability, compressive, flexural, and tensile strength of concrete when waste glass powder is used as a partial substitute for fine aggregate. Additionally, it provides a comprehensive summary of the current state of knowledge on this topic, evaluating the outcomes of previous studies, methodologies, and limitations. This review paper aids in understanding the progress made in this field and identifying areas that require further investigation. Overall, preparing a review paper on the performance of waste glass powder as a partial substitution of fine aggregate in concrete consolidates existing knowledge, evaluates performance, identifies benefits, challenges, and guides future research.

1. Introduction

Concrete is significantly utilized in the field of construction, making it one of the most employed building materials. However, the production of conventional concrete relies heavily on the extraction of natural resources, such as sand and gravel, leading to the deterioration and reduction of natural resources. Recently, there has been an increasing attention on the development of sustainable alternatives for conventional concrete by incorporating waste materials as partial replacements for conventional ingredients. One such waste material that shows promise as a sustainable alternative is waste glass powder. Glass waste, generated from various sources such as glass bottles, containers, and windows, poses a significant environmental challenge due to its slow decomposition rate and limited recycling options. However, several research have demonstrated that incorporating waste glass powder as a partial replacement for the fine aggregate in concrete offers potential benefits in terms of both performance and sustainability [1-2]. Adding waste glass powder to concrete mixtures presents an opportunity to reduce the consumption of natural resources and mitigate the impact on the environment caused by the disposal of glass waste.

By diverting waste glass from landfill sites and integrating it into the production of concrete, this method encourages a circular economy and supports the fundamentals of sustainable construction [3]. This review aims to provide a comprehensive summary of the earlier research on the performance of waste glass powder as a partial substitution of fine aggregate in sustainable concrete. This article investigates the mechanical properties of the concrete mixture, including compressive, tensile and flexural strength of concrete as well as its workability and durability characteristics. By critically evaluating previous studies, this review aims to consolidate existing knowledge, identify gaps that need to be addressed, and offer insights into the challenges and opportunities associated with the implementation of waste glass powder in concrete production. Furthermore, this review explores the benefits and challenges associated with incorporating waste glass powder as a partial substitute for fine aggregate. It emphasizes the favourable outcomes, including enhanced sustainability through waste reduction and resource conservation. Moreover, this review paper identifies research gaps and areas that require further investigation.

2. An Overview on the preparation and properties of waste glass in Concrete

Waste glass refers to glass materials that are discarded or considered as waste, typically originating from various sources such as bottles, windows, windshields, and other glass products. Instead of being sent to landfills, waste glass can be recycled and incorporated into concrete as a sustainable and environmentally friendly alternative [4-5]. Each year, millions of tons of glass bottles are discarded in landfills, leading to significant environmental risks [6-7]. Numerous research studies have suggested that diverse forms of waste glass hold the potential for eco-friendly recycling within the concrete industry [8-10]. It is important to emphasize that the use of waste glass in concrete requires proper processing, such as crushing and sieving, to obtain the desired particle size and quality. Additionally, the specific proportions and characteristics of waste glass used in concrete should be carefully considered and tested to ensure the desired performance and compatibility with the cementitious matrix. Figure 1 depicts the different stages involved in the process of preparing waste glass [11].

Figure 1. Process of preparing waste glass [11]

The process of preparing glass powder from bottles is started with the collection of empty glass bottles, and sort them based on colour. Once the bottles are sorted, they need to be crushed into smaller pieces. The bottles are fed into the crushing machine, which breaks them down into smaller fragments. After the bottles are crushed, the resulting fragments are further processed to obtain a fine glass powder. The crushed glass is typically transferred to a grinding mill, where it undergoes further mechanical grinding. The grinding process reduces the glass fragments into a powdered form. The size of the glass particles can be controlled to achieve the desired fineness. To ensure uniformity and remove any larger particles or impurities, the glass powder is often sieved.

After sieving, the glass powder may undergo a drying process to remove any moisture present. Drying can be achieved through methods such as air drying or using specialized drying equipment. Properly dried glass powder is essential for subsequent processing and applications. In recent years, various investigations have been carried out to determine the use of recycled glass in concrete [12-16]. Siddika et al. [17] conducted a study which highlights the physical properties of glass waste, making it a viable option for substituting fine aggregate in concrete mixtures. To ensure the successful utilization of waste glass as a substitute, it is essential to examine its specific physical characteristics. Glass typically has a density ranging from approximately 1600 to 1700 kg/m^3 and a specific gravity between 2 and 2.6, although these qualities can vary depending on the composition of the glass. Introducing glass into concrete mixtures for engineering purposes is likely to result in a reduction in density.

Several studies have provided evidence showing that the addition of waste glass aggregates leads to a drop in the density of concrete. For example, Qaidi et al. [18] indicated that the density of concrete mixes containing 50% and 100% waste glass decreased by 1% and 2%, respectively, when compared to Ordinary Portland Cement (OPC). However, it is worth mentioning that the hydration process of cement incorporating glass powder occurs at a relatively slower rate compared to OPC. According to Ali and Al-Tersawy [19], it is crucial to carefully determine the appropriate level of glass replacement and consider distribution of particle sizes of waste glass to achieve optimal performance in concrete applications. As per this research, there is a lack of consistency regarding the suggested particle size, dosage, and compatibility with various cementitious systems for waste glass powder.

3. Properties of concrete containing waste glass

This section considers different characteristics of concrete that include workability, compressive strength, tensile strength, flexural strength, and the durability of concrete incorporating waste glass.

3.1. Workability

Workability relates to how easily concrete can be mixed, placed, and completed. It is influenced by several variables such as the volume of water used, the composition of the mixture, and the inclusion of additives. This section focuses on investigating the influence of using waste glass powder as a partial replacement for fine aggregate on the workability of concrete. Several studies have investigated that the addition of waste glass powder can lead to changes in the workability properties of the fresh concrete [20-22]. Some studies suggest that as the ratio of waste glass powder increases, the workability of the concrete may decrease due to the improved surface characteristics and morphology of the glass particles [23-24]. This may result in higher friction between particles, leading to reduced flowability and increased viscosity of the concrete mix. The workability of concrete is significantly impacted by the size and shape of waste glass powder particles. Smaller waste glass particles tend to improve workability compared to coarser particles. Smaller particles can better fill the voids between larger aggregates, enhancing the lubricating influence and minimizing internal friction. Furthermore, rounded particles of waste glass powder could enhance workability more than angular or irregular particles [25-26].

Ekop et al. [27] performed a study to examine workability of concrete when waste glass particles were applied as a partial replacement for fine aggregate. The research involved varying percentages of waste glass particles in place of fine aggregate. The results demonstrated that incorporating waste glass powder into concrete mixtures can increase the need for water due to the porous characteristics of the glass particles. To reduce this impact and maintain workability, researchers have investigated employing superplasticizers that reduce water content. Superplasticizers have the potential to improve the dispersion of cement particles, then improving the flowability of the mix, even in the presence of added waste glass powder [28-29]. In short, several studies have suggested that a partial replacement of up to 20% of fine aggregate with waste glass powder can be viable without causing considerable workability issues [20-24]. However, surpassing this replacement level, careful modifications in mix design and the incorporation of additives may be necessary to uphold sufficient workability.

3.2. Compressive strength of concrete

The compressive strength of concrete, a crucial mechanical property, is influenced by various factors including the characteristics of its components, the ratio of the mixture, the compaction technique employed, the presence and extent of contaminants, as well as additional measures taken during the placement and curing process. Kumar and Nagar et al. [30] conducted a study on the substitution of fine aggregate in concrete with glass powder. They examined various replacement rates ranging from 5% to 50%, increasing by increments of 5%. The researchers observed that incorporating an optimal proportion of 25% waste glass particulate in the concrete mixture led to an improvement in compressive strength compared to regular concrete. According to this study, the effect of various factors, such as the percentage of waste glass powder, particle size distribution, and the use of additional on the mechanical characteristics of concrete needs further exploration.

Moving on, Islam et al. [31] conducted experiments to assess the effectiveness of glass in both mortar and concrete. After conducting tests on the compressive strength of concrete, they discovered that both the recycled glass mortar and concrete samples exhibited improved results in comparison to the control samples. It was found that replacing 20% of the fine aggregate with waste glass was a viable option considering both cost and environmental factors. In another research, Baikerikar et al. [32] carried out research to examine the influence of integrating waste glass powder as a partial substitute for sand on compressive strength of concrete. The researchers investigated different concrete mixes, including the control mix, as well as mixes which involved replacing 5%, 10%, 15%, 20%, and 25% of the fine aggregate with glass powder. Based on the results, the mixture containing 10% glass powder was identified as the optimum choice in term of compressive strength. Overall, this research proposed a novel and environmentally friendly concrete with enhanced performance by utilizing an optimized combination of waste glass powder as a substitution for fine aggregate.

Olofinnade et al. [33] replaced the fine aggregate with waste glass at various percentages: 25%, 50%, 75%, and 100% by weight. The results indicated that the concrete with 25% glass content exhibited the highest percentage of improve in compressive strength across all curing durations. Conversely, the concrete specimens containing 75% and 100% glass content demonstrated the lowest compressive strength. The extent of the reduction in compressive strength can vary depending on the proportion of fine aggregate replaced with waste glass powder. Several researchers performed experiments to establish the optimal replacement that strikes a balance between the targeted strength and the sustainable utilization of waste materials [34-35]. Compressive strength may improve at lower replacement ratios, which can help to reduce the negative impacts of glass powder.

In another study, Selvakumar et al. [36] investigated the impact of substituting glass powder for a portion of the fine aggregate in basalt fiber reinforced concrete. The researchers investigated various mixes, including the control mix, and mix with 5% and 10% glass powder. Based on the laboratory results, it was demonstrated that replacing 10% of the fine aggregate with glass powder led to improved strength properties in comparison to conventional concrete. Furthermore, incorporating glass powder as a substitute for fine aggregate in this study led to a decrease in density and an improvement in workability characteristics.

Next, Khan et al. [37] studied the use of waste glass substitutes in varying percentages, including 0%, 20%, and 40%. The outcomes of the compressive strength experiments indicated that the optimal percentage of waste glass was 20% at 28 days. Similarly, Warnphen et al. [38] conducted a study and also found that the optimal ratio of waste glass was 20%, resulting in a 7.71% increase in compressive strength compared to the control mixture. In the research conducted by Malik [39], various tests were carried out to evaluate the strength properties of the specimens. The compressive strength measured after 28 days was 25% higher than the reference mix, which corresponded to a concrete mix containing 20% waste glass instead of fine aggregate. Nevertheless, the concrete mixture containing 40% waste glass exhibited a lower compressive strength compared to the reference mixture.

In a different research, Ismail and AL-Hashmi [40] carried out a study in which waste glass was applied as a replacement for sand at varying rates of 10%, 15%, and 20%. Their findings showed that the sample with a 20% glass waste replacement exhibited a compressive strength that was 4.23% higher than the control sample after 28 days. It was found that waste glass possesses pozzolanic characteristics, indicating its potential to react with calcium hydroxide when in contact with water and form hydrated calcium silicate, which is an essential element in concrete.

The calcium silicate hydrate produced by the reaction between glass powder and calcium hydroxide in the cement mixture can enhance the durability of concrete, which contributes to the strength of the concrete over time. This process can mitigate the initial weakening of strength. Modifying the concrete mixture and incorporating chemical additives can improve the strength of concrete integrating waste glass powder [41-42]. Overall, the incorporation of waste glass powder as a partial substitution for fine aggregate tends to initially a decrease in compressive strength. By the way, the outcomes exhibit a range of results, with certain studies representing an improve in compressive strength at particular waste glass powder replacement levels, while others show a reduction. This phenomenon can be primarily attributed to the glass powder particles having a lower density and reduced reactivity when compared to sand. This difference in density and chemical reactivity can result in less compact microstructure and a weaker bond between the cement matrix and the glass particles.

3.3. Flexural strength of concrete

This section is focused on the existing literature involving the influence of incorporating waste glass powder on the flexural strength of concrete that significantly affects the structural integrity. Flexural strength represents the ability of concrete to withstand bending forces without experiencing significant deformation or failure. This property is influenced by various factors, encompassing the type and quality of materials used in the mixture [43]. Several research have investigated the impact of waste glass powder on the flexural strength of concrete [44-46]. The outcomes exhibit diversity, with some studies reporting an improvement in flexural strength at certain levels of waste glass powder replacement, while others demonstrate a decrease. The influence of waste glass power on flexural strength is linked to factors such as particle size, morphology, dosage, and the composition of the mixture.

The dimensions and configuration of waste glass powder particles play a crucial role in determining their influence on flexural strength. Finer particles with smoother surfaces can improve the interfacial bond between the cement and aggregates, which could lead to providing higher flexural strength. On the other hand, larger or non-uniformly shaped particles may create weaknesses within the matrix, leading to a reduction in flexural strength.

In a study conducted by Abdallah and Fan [47], flexural strength tests were carried out on concrete specimens at different ages: 7, 14, and 28 days. The results indicated that the addition of waste glass in the concrete mixture led to an overall enhancement in flexural strength. Specifically, after 28 days, the flexural strength exhibited a respective increase of 3.54%, 5.03%, and 8.92% when the glass content was raised by 5%, 15%, and 20% respectively. This improvement can be attributed to the occurrence of pozzolanic reactions, which seemed to accelerate over time, counteract the hardening process, and contribute to the enhanced flexural strength. Next, Keryou and Ibrahim [48] carried out a study to investigate the impact of waste glass on the flexural strength of concrete at 7 and 28 days. The findings showed that incorporating 25% waste glass had the most significant effect, resulting in the highest increase in flexural strength. Specifically, the flexural strength exhibited a 44% increase at 7 days and a 31% increase at 28 days compared to the control specimens.

According to [49] attaining the desired flexural strength when incorporating waste glass powder requires precise dosing and meticulous mix design. Certain studies indicates that a partial replacement of fine aggregate with waste glass powder usually within the range of 10% to 20%, can lead to improved flexural strength [50-51]. However, surpassing this range might require adjustments in mixture proportions and potentially incorporating extra strengthening agents to maintain acceptable level of flexural performance.

3.4. Tensile strength of concrete

Properly scattered glass particles can improve the microarchitecture of the concrete, resulting in increased cohesion between its components and an improve in tensile strength. This phenomenon can be explained by the pozzolanic reaction between the glass particles and the cement matrix, leading to the formation of extra cementitious compounds that improve the tensile strength [52-53]. Incorporating waste glass powder can influence the arrangement of particles in the concrete mixture.

Properly sized and evenly distributed glass particles can fill voids between larger particles, resulting in a more condensed microstructure and lead to increased tensile strength.

The research conducted by Wang et al. [54] examined the feasibility of using unwashed waste glass fines as a substitute for sand at a 10% replacement level in laboratory settings. Slight disparities in tensile strength were noticed between concrete samples with and without 10% replacement of waste glass fines. In general, this investigation concluded that the impact of impurities present in waste glass fines can be disregarded when they are utilized as a substitute for natural sand at a 10% replacement rate. This study suggests that additional research is essential to acquire a more comprehensive understanding of the long-term performance of concrete that incorporates unwashed waste glass fines.

From the research done by [55-56], waste glass powder has the potential to enhance the bonding between the cement matrix and fine aggregates. This improved adhesion at the interface's zones can lead to higher tensile strength of concrete. Although several studies have explored different replacement levels of fine aggregate with waste glass powder to determine the optimal percentage that provides the best balance for improving tensile strength, further research is required to identify this optimal percentage [52-56]. While waste glass powder has encouraging effects on tensile strength, it is necessary to consider potential challenges, including the inconsistency in waste glass composition, the risk of workability hindrance, and the need to optimize mix designs to ensure reliable results.

3.5. Durability of concrete

Durability of concrete refers to its capability to resist different environmental and mechanical factors over time without considerable deterioration and maintaining its structural and functional characteristics. Adequate mix design, proper curing methods and the incorporation of appropriate additives can enhance the durability of concrete. An essential aspect of durability is the resistance of concrete to withstand the penetration of chloride ions, a parameter that can lead to the corrosion of the reinforcing steel. Addition of waste glass powder can affect the entrance of chloride ions into the concrete, reducing the potential for corrosion and enhancing the service life of structures [57-58].

Alkali-silica reaction represents a reaction that may occur between certain types of aggregate and the alkali substance present in cement. This interaction can result in expansive cracking and a reduce in durability. The potential use of waste glass powder has been studied as a strategy to mitigate alkali-silica reaction [59-60]. The inclusion of waste glass powder initiates a chemical reaction that can balance out excessive alkali and decrease the chances of the material expanding.

The deterioration of concrete through sulfate attack, which can occur in sulfate-rich environments, is a concern that should be taken into consideration in concrete. Several researchers have investigated the utilization of waste glass powder to potentially improve the capability of concrete to withstand sulfate attack by reducing permeability and creating a more compact microstructure [61-62].

Carbonation resistance presents another concern linked to the durability of concrete. It takes place when carbon dioxide from the air reacts with calcium hydroxide in concrete, resulting in a reduce in pH and the possibility of corrosion in reinforcing steel. According to several research [63-64], the incorporation of waste glass powder can enhance the carbonation resistance by reducing porosity and improving the durability of the concrete. Moving on, the durability of concrete when faced with freezing and thawing cycles is extremely important, especially in colder regions. Based on various studies, the presence of waste glass powder can influence the freeze-thaw characteristics of concrete by improving the air void structure and decreasing permeability [65-68]. This effect can help in the prevention of frost-induced damage.

4. Conclusion

This review highlights the significant potential of waste glass powder as a partial replacement for fine aggregates in various construction applications. Its incorporation in concrete mixes has proven to have different impacts on workability, strength, and durability properties. According to the previous studies, the effects of incorporating waste glass powder in concrete depend on factors like particle dimensions, shape, dosage, and the utilization of additives. Although higher percentages of replacement with waste glass powder may lead to reduced workability, the application of suitable alterations to the mixture design and use of superplasticizers can help to reduce these effects.

The research findings demonstrate that in general, incorporating waste glass powder tends to a drop in compressive strength when compared to conventional concrete mixes. By the way, compressive, flexural, and tensile strength might experience enhancement in certain instances, while in alternative scenarios, it could exhibit minimal alteration or even reduction. According to the previous studies, accurate adjustments in important factors like particle characteristics, dosage, and mixture composition can lead to sustainable application of waste glass powder in concrete. This can improve mechanical properties and overall structural performance. Also, the results from this review show that, waste glass powder has the capacity to extend the service life and durability of concrete structures by impacting the chloride ion penetration, mitigating alkali-silica reaction, improving freeze-thaw resistance, enhancing sulfate attack resistance, and contributing to carbonation resistance.

Furthermore, the utilization of waste glass powder offers a viable solution for waste management and reduces the demand for natural resources. However, further investigation is needed to optimize the dosage, particle size distribution, and compatibility with different cementitious systems. Overall, the utilization of waste glass powder offers an opportunity to reduce the environmental impact associated with glass waste disposal. By diverting glass waste from landfills and utilizing it in construction, both waste management and resource conservation goals can be achieved simultaneously.

5. References

[1] Paul D, Bindhu K R, Matos A M and Delgado J 2022 Eco-friendly concrete with waste glass powder: A sustainable and circular solution, *Constr. Build. Mater.* **355** 129217
[2] Nassar R, Soroushian P and Sufyanuddin M 2021 Long-term field performance of concrete produced with powder waste glass as partial replacement of cement, Case Stud. *Constr. Mater.* **15** e00745
[3] Elaqra H and Rustom R 2018 Effect of using glass powder as cement replacement on rheological and mechanical properties of cement paste, *Constr. Build. Mater.* **179** 326-335
[4] Mohammadhassani M, Jumaat M Z B, Chemrouk M, Ghasemi A, Hakim S J S and Najmeh R 2011 An experimental investigation of the stress-strain distribution in high strength concrete deep beams, *Procedia Engineering*. **14** 2141-2150
[5] Lim J L G, Raman S N, Lai F C, Zain M F M and Hamid R 2018 Synthesis of nano cementitious additives from agricultural wastes for the production of sustainable concrete, *J. Clean. Prod.* **171** 1150-1160.
[6] Mhaya A M, Shahidan S, Zuki S S M, Ghasan F H, Azmi M A M, Ismail M and Mirza J 2022 Durability and acoustic performance of rubberized concrete containing POFA as cement replacement, *Sustainability* **14** (23) 15510
[7] Ravanfar S A, Razak H A, Ismail Z and Hakim S J S 2015 A hybrid procedure for structural damage identification in beam-like structures using wavelet analysis, *Adv. Struct. Eng.* **18** (11), 1901-1913
[8] 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.
[9] Noorzaei J, Hakim S J S, Jaafar M S, Abang A A A and Thanoon W A M 2007 An optimal architecture of artificial neural network for predicting compressive strength of concrete, *Indian Concr. J.* **81** (8), 17–24
[10] Hakim S J S, Razak H A and Ravanfar S A 2015 Ensemble neural networks for structural damage identification using modal data, *Int. J. Damage Mech.* **25** (3) 400-430
[11] Mhaya A M, Baharom S and Ghasan F H 2022 Improved strength performance of rubberized concrete: Role of ground blast furnace slag and waste glass bottle nanoparticles amalgamation, *Constr. Build. Mater.* **342** Part B 128073
[12] Rashid K, Hameed R, Ahmad H A, Razzaq A, Ahmad M and Mahmood A 2018 Analytical framework for value added utilization of glass waste in concrete: Mechanical and environmental performance, *J. Waste Manag.* **79**, 312–323

[13] Mhaya A M, Algaifi H A, Shahidan S, Zuki S S M, Azmi M A M, Ibrahim M H W and Ghasan F H 2022 Systematic evaluation of permeability of concrete incorporating coconut shell as replacement of fine aggregate, *Mater*. **15** (22) 7944
[14] Milad A, Majeed S A, Adwan I, Khalifa N A and Yusoff N I M 2022 Adaptive neuro fuzzy inference system for predicting flexible pavement distress in tropical regions, *J Eng Sci Technol*, **17**(1) 1-14
[15] Ravanfar S A, Abdul Razak H, Ismail Z and Hakim S J S 2016 A Hybrid wavelet based–approach and genetic algorithm to detect damage in beam-like structures without baseline data, *Exp. Mech*. **56**(8) 1411-1426
[16] Azan M E H M and Hakim S J S 2022 A Study on the mechanical properties of concrete containing fly ash as partial cement replacement-a critical review, *Recent Trends in Civil Engineering and Built Environment.* **3**(1) 641-649
[17] Siddika A, Hajimohammadi A, Ferdous W and Sahajwalla V 2021 Roles of waste glass and the effect of process parameters on the properties of sustainable cement and geopolymer concrete-a state-of-the-art review, *Polym. J.* **13**(22) 3935
[18] Qaidi S, Najm H M, Abed S M, Ozkılıç Y O, Dughaishi H, Alosta M, Sabri M M S, Alkhatib F and Milad A 2022 Concrete containing waste glass as an environmentally friendly aggregate: a review on fresh and mechanical characteristics, *Mater*. **15**(18) 6222
[19] Ali E E and Al-Tersawy S H 2012 Recycled glass as a partial replacement for fine aggregate in self-compacting concrete, *Constr. Build. Mater*. **35** 785–791.
[20] Xu J, Kang A, Wu Z, Xiao P and Gong Y 2023 Evaluation of workability, microstructure and mechanical properties of recycled powder geopolymer reinforced by waste hydrophilic basalt fiber, *J. Clean. Prod.* **396** 136514
[21] Asgarian A, Roshan N and Ghalehnovi M 2023 The Strength, Microstructure, and ecological assessment of concrete mix incorporating waste glass powder and polypropylene fiber, *Constr. Build. Mater*. **371** 130726
[22] Celik A I, Tunc U, Bahrami A, Karalar M, Mydin M A O, Alomayri T and Ozkılıc Y O 2023 Use of waste glass powder toward more sustainable geopolymer concrete, *J. Mater. Res. Technol*. **2**(4) 8533-8546
[23] Jaini Z M, Rum R H M, Hakim S J S and Mokhatar S N 2023 Application of foamed concrete and cold-formed steel decking as lightweight composite slabs: experimental study on structural behaviour, *Int. J. Integr. Eng*. **15**(2) 91-103
[24] Selvasofia S DA, Dinesh A and Sarath B V 2021 Investigation of waste marble powder in the of sustainable concrete, *Mater. Today: Proc*. **44** 4223- 4226
[25] Mohammed T K and Hama S M 2023 Effect of combination of waste glass powder and plastic aggregate on structural behavior of reinforced concrete beams, *Structures.* **52** 83–103
[26] Ramdania S, Guettalaa A, Benmalekb M L and Aguiarc J B 2019 Physical and mechanical performance of concrete made with waste rubber aggregate, glass powder and silica sand powder, *J. Build. Eng.* **21** 302–311
[27] Ekop I E, Okeke C J and Inyang E V 2022 Comparative study on recycled iron filings and glass particles as a potential fine aggregate in concrete, *Resour. Conserv. Recycl*. **15** 200093
[28] Elsayed M, Abdallah S R, Said M and Abdelazim A 2023 Structural performance of recycled coarse aggregate concrete beams containing waste glass powder and waste aluminum fibers, *Case Stud. Constr. Mater*. **18** e01751
[29] Salman A M, Akinpelu M A, Yahaya I T and Salami H M 2023 Workability and strengths of ternary cementitious concrete incorporating calcined clay and limestone powder, *Mater. Today: Proc*. **86** 51–58
[30] Kumar S and Nagar D B 2017 Effects of waste glass powder on compressive strength of concrete, *Int. J. Sci. Res*. **1**(4) 289-298
[31] Islam G M S, Rahman M H and Kazi N 2017 Waste glass powder as partial replacement of cement for sustainable concrete practice, *Int. J. Sustain. Built Environ*. **6**(1) 37–44
[32] Baikerikar A, Mudalgi S and Ram V V 2023 Utilization of waste glass powder and waste glass sand in the production of eco-friendly concrete, *Constr. Build. Mater***. 377** 131078

[33] Olofinnade O M, Ede A N, Ndambuki J M, Ngene B U, Akinwumi I I and Ofuyatan O 2018 Strength and microstructure of eco-concrete produced using waste glass as partial and complete replacement for sand, *Cogent Eng*. **5**(1) 1-19
[34] Gutierrez R M, Caicedo M A V and Aponte L A G 2020 Alkali-activated metakaolin mortars using glass waste as fine aggregate: Mechanical and photocatalytic properties, *Constr. Build. Mater*. **235** 117510
[35] Khan M N N and Sarker P K 2020 Effect of waste glass fine aggregate on the strength, durability and high temperature resistance of alkali-activated fly ash and GGBFS blended mortar, *Constr. Build. Mater*. **263** 120177
[36] Selvakumaran M, Geetha S, Rangan S K, Sithrubi T and Sathyashriya K 2021 Effect of glass powder as partial fine aggregate replacement on properties of basalt fibre reinforced concrete, *Mater. Today: Proc*. **43** 1460–1464
[37] Khan Q S, Sheikh M N, McCarthy T J, Robati M and Allen M 2019 Experimental investigation on foam concrete without and with recycled glass powder: A sustainable solution for future construction, *Constr. Build. Mater*. **201** 369–379
[38] Warnphen H, Supakata N and Kanokkantapong V 2019 The reuse of waste glass as aggregate replacement for producing concrete bricks as an alternative for waste glass management on koh sichang, *Eng. J*. **23** (5) 43-58
[39] Malik M I 2013 Study of concrete involving use of waste glass as partial replacement of fine aggregates, *IOSR j. eng*. **3** (7) 8–13
[40] Ismail Z Z and Hashmi E A 2009 Recycling of waste glass as a partial replacement for fine aggregate in concrete, *J. Waste Manag*. **29** 655–659
[41] Dalal S P, Dalal P, Motiani R and Solanki V 2022 Experimental investigation on recycling of waste pharmaceutical blister powder as partial replacement of fine aggregate in concrete, *Resour. Conserv. Recycl*. **14** 200076
[42] Gautam L, Jain J K, Alomayri T, Meena N and Kalla P 2022 Performance evaluation of self-compacting concrete comprising ceramic waste powder as fine aggregate, *Mater. Today: Proc*. **61** 204–211
[43] Mustafa T S, Mahmoud A A, Mories E M and Beshlawy S A 2023 Flexural behavior of reinforced concrete slabs containing recycled glass powder and steel fibers, *Structures*. **54** 1491–1508
[44] Taher S M S, Saadullah S T, Haido J H and Tayeh B A 2021 Behavior of geopolymer concrete deep beams containing waste aggregate of glass and limestone as a partial replacement of natural sand, *Case Stud. Constr. Mater*. **15** e00744
[45] Bao S, Zhang Y, Liu H, Zhang W and Zeng K 2023 Flexural behavior of the UHPCC containing glass powder as partial substitute of cement/silica fume, *Constr. Build. Mater*. **365** 130142
[46] Mokhatar S N, Yusoff A R M, Budiea A M A and Hakim S J S 2022 A Review: study on spent garnet as construction material, *Int. J. Integr. Eng*. **14** (5) 73-80
[47] Abdallah S and Fan M 2014 Characteristics of concrete with waste glass as fine aggregate replacement, *Int. J. Eng. Res. Technol*. **2**(6) 11–17
[48] Keryou A B and Ibrahim G J 2016 Effect of Using Windows Waste Glass as Fine Aggregate on Some Properties of Concrete, *Tikrit Journal of Engineering Sciences*. **23**(3) 47–54.
[49] Srikanth K S and Lalitha G 2022 Mechanical performance of sustainable ternary blended self-compacting concrete with waste crushed glass, *Mater. Today: Proc*. **60** 394–398
[50] Manikandan P and Vasugi V 2022 Potential utilization of waste glass powder as a precursor material in synthesizing ecofriendly ternary blended geopolymer matrix, *J. Clean. Prod*. **355** 31860
[51] Wang T, Nicolas R S, Kashani A and Ngo T 2022 Sustainable utilisation of low-grade and contaminated waste glass fines as a partial sand replacement in structural concrete, *Case Stud. Constr. Mater*. **16** e00794
[52] Grubesa I N, Barisic I, Stanic M H and Grdic D 2023 Effect of CRT glass and TiO2 as a replacement for fine aggregate and cement on properties of pervious concrete paving flags, *Constr. Build. Mater*. **397** 132426

[53] Tahwia A M, Essam A, Bassam A, Tayeh B A and Elrahman M A 2022 Enhancing sustainability of ultra-high performance concrete utilizing high-volume waste glass powder, *Case Stud. Constr. Mater*. **17** e01648
[54] Wang T, Nicolas R S, Kashani A and Ngo T 2022 Sustainable utilisation of low-grade and contaminated waste glass fines as a partial sand replacement in structural concrete, *Case Stud. Constr. Mater*. **16** e00794
[55] Deng Y, Yan C, Zhang J, Yin L, Liu S and Yan Y 2022 Preparation and mechanical characterization of engineered cementitious composites with high-volume fly ash and waste glass powder, *J. Clean. Prod*. **333** 130222
[56] Hakim S J S, Razak H A, Ravanfar S A and Mohammadhassani M 2014 Structural damage detection using soft computing method, *Structural Health Monitoring*. **5** 143-151
[57] Srikanth K S and Lalitha G 2022 Durability properties of self-compacting concrete partial replacement of fine aggregate with waste crushed glass, *Mater. Today: Proc*. **51** 2411–2416
[58] Khalifa N A, Zulkiple A, Alfughi A G A, Attboli I A A and Ghammeid A S A 2019 Critical review of flexible pavement maintenance management systems, *Int. j. eng. Technol*. **8**(2) 95-101
[59] Fanijo E O, Kassem E and Ibrahim A 2021 ASR mitigation using binary and ternary blends with waste glass powder, *Constr. Build. Mater*. **280** 122425
[60] Yin W, Li X, Chen Y, Wang Y, Xu M and Pei C 2023 Mechanical and rheological properties of High-Performance concrete (HPC) incorporating waste glass as cementitious material and fine aggregate, *Constr. Build. Mater*. **387** 131656
[61] Tanwar V, Bisht K, Kabeer K I S A and Ramana P V 2021 Experimental investigation of mechanical properties and resistance to acid and sulphate attack of GGBS based concrete mixes with beverage glass waste as fine aggregate, *J. Build. Eng*. **41** 102372
[62] Alkubati, M A, Khalifa N A and Al-barakani H A 2023 An overview of public transport reliability studies using a bibliometric analysis, *Ain Shams Engineering Journal.* **14** 101908.
[63] Liu Z, Shi C, Shi C, Tan X and Meng W 2022 Recycling waste glass aggregate in concrete: Mitigation of alkali-silica reaction (ASR) by carbonation curing, *J. Clean. Prod*. **370** 133545
[64] Lyu H, Hao L, Li L, Zhang S and Poon C S 2023 The development of sustainable cement pastes enhanced by the synergistic effects of glass powder and carbonation curing, *J. Clean. Prod*. **418** 138237
[65] Kim J, Moon J H, Shim J W, Sim J, Lee H G and Zi G 2014 Durability properties of a concrete with waste glass sludge exposed to freeze-and-thaw condition and de-icing salt, *Constr. Build. Mater.* **66** 398–402
[66] Mokhatar S N, Mutalib N A, Zabiddin M Z I, Hadipramana J and Hakim S J S 2023 Strength performance of reinforced concrete beam containing waste tire rubber and local waste material, *IOP Conference Series: Earth and Environmental Science* **1205** 012046
[67] Mohammadhasani M, Hakim S J S, Jameel M, Kamarudin A F, Mokhatar S N and Budiea A M A 2023 Effect of infilled walls on the performance of steel frame structures, *Int. J. Integr. Eng*. **15**(2) 79-90
[68] Yasouj S E M and Ghaderi A 2020 Experimental investigation of waste glass powder, basalt fibre, and carbon nanotube on the mechanical properties of concrete, *Constr. Build. Mater*. **252** 119115

Acknowledgments

This research is supported by University Tun Hussein Onn Malaysia (UTHM) through Tier 1 Grant Research [vote Q345].