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Characterization of Waste Glass as Fine Aggregate and Cement Replacement in Concrete

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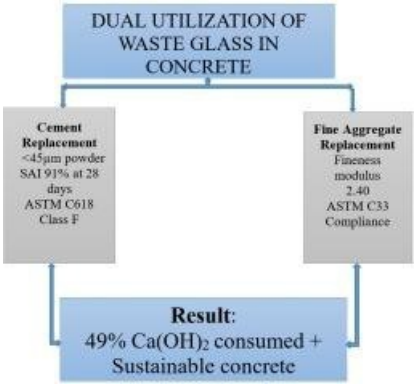
Abstract

This study characterizes waste glass for dual utilization as fine aggregate and cement replacement in concrete. Waste glass was crushed and sieved to conform to ASTM C33 grading for fine aggregate, with fineness modulus of 2.40. Glass powder passing 45 µm was evaluated as supplementary cementitious material per ASTM C618. Strength Activity Index at 20% cement replacement was 78% at 7 days and 91% at 28 days, exceeding the 75% minimum requirement. XRD and TGA confirmed 49% consumption of $Ca(OH)_2$ at 28 days through pozzolanic reaction. Results demonstrate that processed waste glass meets code requirements for sustainable concrete production.

Keywords: Waste glass; Supplementary cementitious material; Fine aggregate; Strength activity index; Pozzolanic reaction

Introduction

Graphical Abstract



Global municipal solid waste generation exceeds 2 billion tonnes annually, with glass comprising 3-11% by mass depending on region [1-2]. Landfilling of waste glass contributes to environmental burden due to its non-biodegradable nature and high volume. Concurrently, concrete production consumes approximately 70% aggregates by volume and cement manufacturing accounts for 7-8% of global CO_2 emissions [3;4].

Utilization of waste glass as aggregate and

supplementary cementitious material offers a dual solution to waste management and natural resource depletion [5;6]. Ground glass powder exhibits pozzolanic activity due to high amorphous silica content, enabling partial replacement of Portland cement [7-12]. As fine aggregate, crushed glass can substitute natural sand if grading conforms to ASTM C33 requirements [13].

Despite extensive research on glass powder as cement replacement, limited studies provide comprehensive characterization of waste glass for dual application as both fine aggregate and cement substitute using code-based test methods. This study addresses this gap by characterizing waste glass through Strength Activity Index per ASTM C311, XRD, TGA, and sieve analysis per ASTM C33 to ascertain its suitability for concrete applications. The findings provide practical guidance for waste glass valorisation in sustainable construction.

Cement

Ordinary Portland Cement Type I conforming to ASTM C150 was used throughout the study. Chemical composition is presented in Table 1[14].

Waste glass

Post-consumer waste glass was collected, washed, and oven-dried at 105 °C for 24 h.

For fine aggregate application, glass was crushed using a jaw crusher and sieved through 4.75 mm to 150 µm sieves to meet ASTM C33 grading requirements [13].

For cement replacement, dried glass was ground in a Los Angeles abrasion machine for 20 h and sieved to obtain powder passing 45 µm sieve. This fineness complies with ASTM C618 requirements for supplementary cementitious materials [15].

Fine aggregate

Natural river sand conforming to ASTM C33 was used as control fine aggregate. Sand was oven-dried and sieved through 4.75 mm sieve to remove oversized particles before mixing.

Test methods

Waste glass was characterized using Strength Activity Index, XRD, TGA, and sieve analysis to assess suitability as fine aggregate and cement replacement.

Strength Activity Index

SAI was determined per ASTM C311 using 50 mm mortar cubes [16]. Control mix contained 100% OPC. Test mix replaced 20% of cement with glass powder by mass, per ASTM C618 Class F requirements.

Six cubes each were cast for control and test mixes. Specimens were demoulded after 24 h and cured in saturated lime water at 23.0 ± 2.0 °C. Compressive strength was tested at 7 and 28 days per ASTM C39 [17]. Three cubes were tested at each age.

SAI was calculated as:

$$SAI = \frac{A}{B} \times 100\%$$

Where A = average compressive strength of test mix, MPa
B = average compressive strength of control mix, MPa

XRD and TGA

Paste samples with 20% glass powder replacement were cured for 28 days, ground to < 150 μm, and oven-dried at 105 °C for 24 h.

XRD analysis was performed using Shimadzu XRD-6000 diffractometer with Cu Kα radiation (λ = 1.54056 Å) at 40 kV and 30 mA. Scan range was 5° to 90° 2θ at 0.5°/min [18].

TGA was conducted using LINSEIS L81-II under nitrogen flow of 30 ml/min. Samples were heated from 30 °C to 1000 °C at 10 °C/min. $Ca(OH)_2$ content was quantified from mass loss between 400 °C and 600 °C [19].

Sieve analysis

Particle size distribution of crushed glass was determined per ASTM C136. Fineness modulus of glass fine aggregate was 2.55, which conforms to ASTM C33 limits of 2.3 to 3.1 [13].

Results and Discussion

This section presents chemical composition, phase identification, pozzolanic activity of glass powder, and sieve analysis of glass fine aggregate.

Chemical composition

Chemical composition of OPC and glass powder is given in Table 1. Glass powder contains 68.5% SiO_2, 1.44% Al_2O_3, and 0.78% Fe_2O_3. Sum of $SiO_2 + Al_2O_3 + Fe_2O_3$ = 70.72%, which exceeds the 70% minimum for Class F pozzolan per ASTM C618. High amorphous SiO_2 content promotes pozzolanic reaction with $Ca(OH)_2$ to form C-S-H gel. CaO content of glass powder is 9.02% vs 68.7% for OPC, confirming its pozzolanic rather than hydraulic nature [20].

Table 1: Chemical composition of glass powder and OPC

Chemical composition	**SiO_2**	**AL_2O_3**	**Fe_2O_3**	**Na_2O**	**CaO**	**MgO**	**TiO_2**	**K_2O**	**SO_3**
Cement (mass %)	17.8	3.52	2.99	ND	68.7	1.68	0.191	0.899	4.17
Glass powder (mass %)	68.5	1.44	0.780	15.9	9.02	3.48	0.0803	0.541	0.243

ND = Not detected. Sum of $SiO_2+Al_2O_3+Fe_2O_3$ for glass powder = 70.72% ≥ 70% per ASTM C618 Class F.

Phase identification by XRD

XRD pattern of glass powder is shown in Fig. 1. A broad diffraction halo between 20° and 35° 2θ confirms amorphous structure. No crystalline peaks were detected, indicating glassy phase. Amorphous silica is reactive with $Ca(OH)_2$ to form additional C-S-H, improving strength and durability [21].

Measurement Conditions

Name	Value	Name	Value
X-Ray generator	40 kV, 30 mA	Scan mode	1D(scan)
Incident primary	None	Scan speed/Duratio...	3.00 °/min
Goniometer	Inplane Goniometer	Step width	0.01 °
Attachment	RxRy	Scan axis	θ/2θ
Filter	None	Scan range	20 ~ 80 °
CBO selection slit	BB	Incident slit	2/3°
Diffracted beam mo...	None	Length limiting slit	10 mm
Detector	D/teX Ultra 250 (H)	Receiving slit #1	Open
Optics attribute	BB	Receiving slit #2	Open

Measured profile view

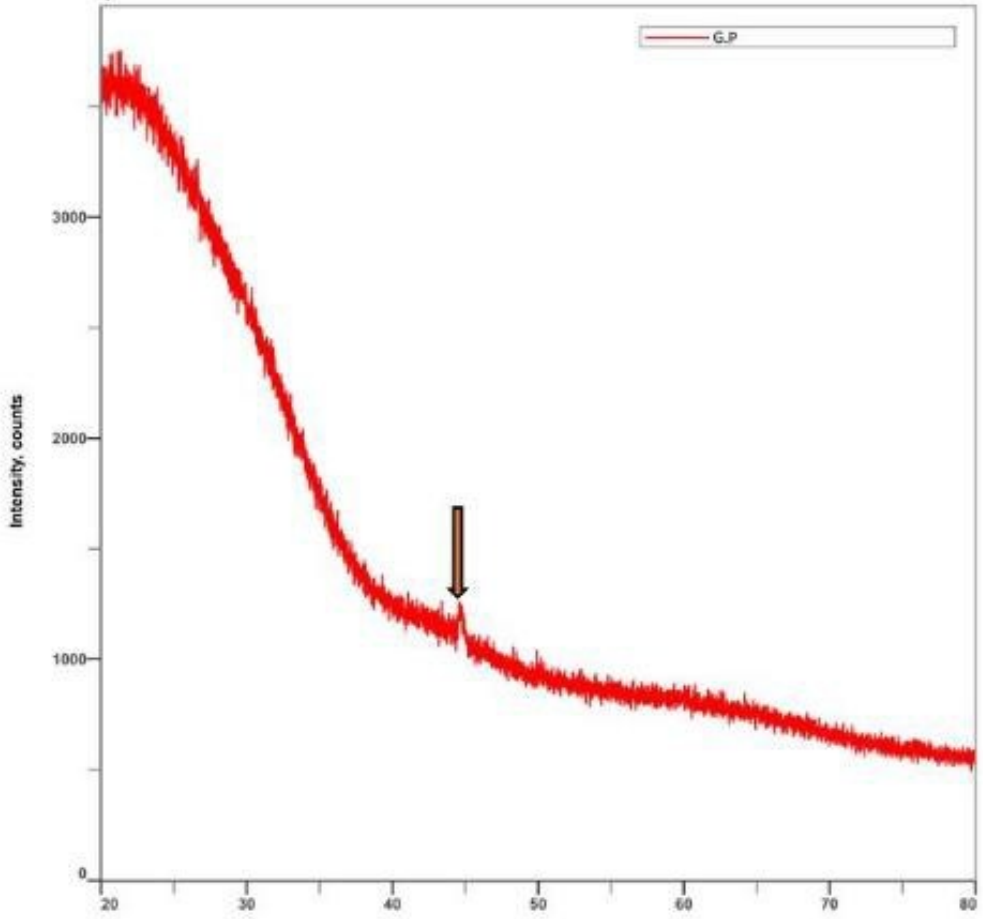


Fig. 1: XRD pattern of glass powder showing amorphous halo

Strength Activity Index

SAI results at 7 and 28 days are shown in Fig. 2. At 20% cement replacement, SAI was 78% at 7 days and 91% at 28 days. Both values exceed the 75% minimum required by ASTM C618 for pozzolanic materials. Lower SAI at 7 days is due to delayed pozzolanic reaction. Strength gain at 28 days confirms glass powder contributes to strength through C-S-H formation [20].

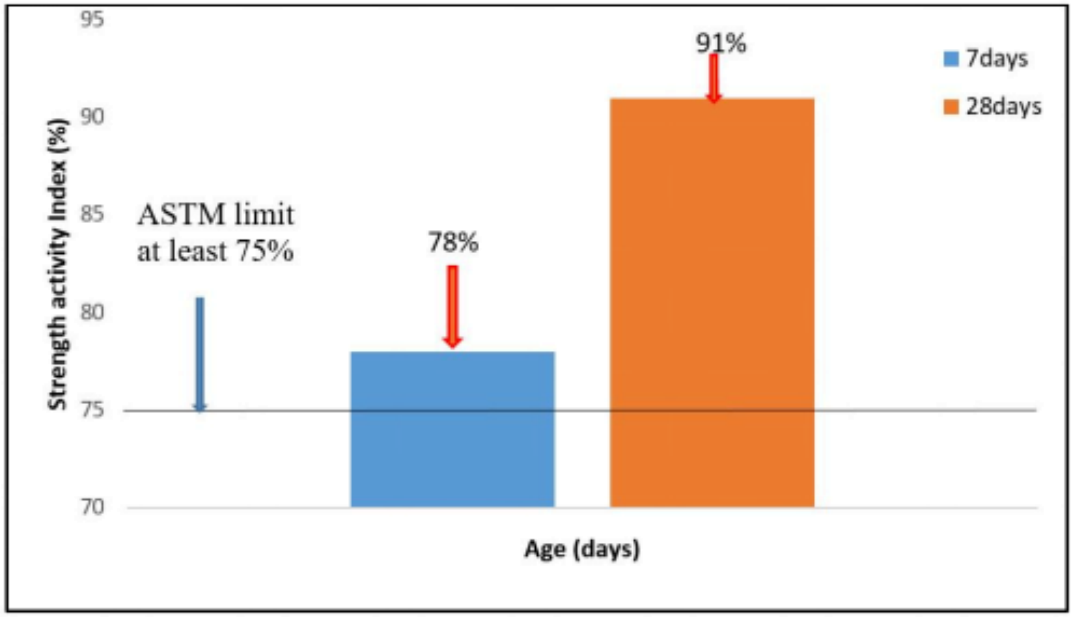


Fig. 2: Strength Activity Index of glass powder at 7 and 28 days

Pozzolanic reaction occurs in 3 stages:

1. Dissolution of $Ca(OH)_2$: $Ca(OH)_2 \rightarrow Ca^{2+} + 2OH^-$
2. Dissolution of amorphous SiO_2: $SiO_2 + 2OH^- + H_2O \rightarrow H_2SiO_4^{2-}$
3. C-S-H formation: $xCa^{2+} + H_2SiO_4^{2-} + 2(x-1)OH^- + (y-x)H_2O \rightarrow xCaO{\cdot}SiO_2{\cdot}yH_2O$

Overall: $Ca(OH)_2 + SiO_2 \rightarrow$ C-S-H [22].

3.1.3.2 XRD of glass powder paste

XRD of 28-day paste with 20% glass powder is shown in Fig. 3. Compared to control, glass powder paste shows reduced $Ca(OH)_2$ peaks and presence of C-S-H. This confirms consumption of $Ca(OH)_2$ through pozzolanic reaction [23].

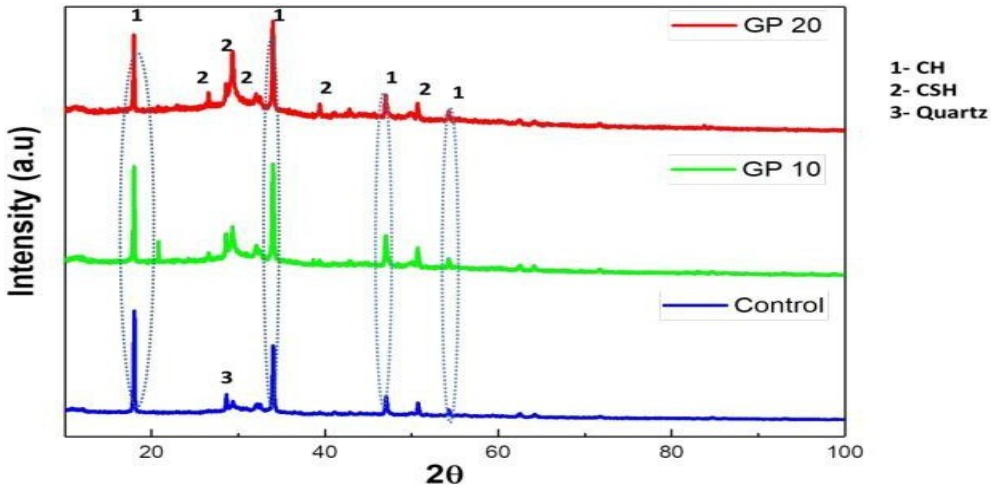


Fig. 3: XRD pattern of control paste vs glass powder paste at 28 days

Thermogravimetric analysis

TGA curves for control, 10% GP, and 20% GP pastes are shown in Fig. 4. Three weight loss stages were observed: 30-400 °C for free water and C-S-H dehydration, 400-600 °C for $Ca(OH)_2$ dehydroxylation, and 600-800 °C for $CaCO_3$ decarbonation [24].

$Ca(OH)_2$ content decreased by 17% for 10% GP and 49% for 20% GP relative to control, as shown in Fig. 5. This reduction confirms pozzolanic consumption of $Ca(OH)_2$ by glass powder.

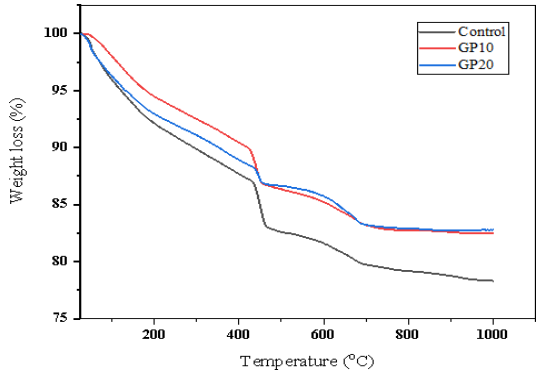


Fig. 4: TGA curves of control and glass powder pastes

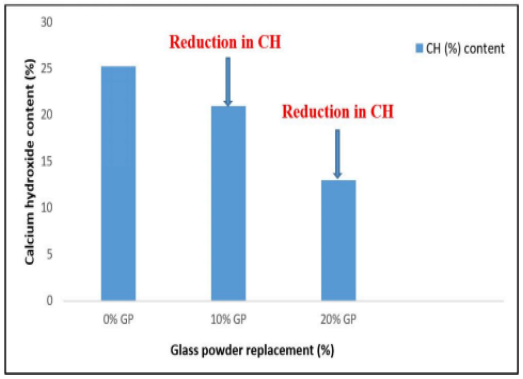


Fig. 5: $Ca(OH)_2$ content in control vs glass powder pastes

Sieve analysis

Particle size distribution of glass fine aggregate is shown in Fig. 6. Fineness modulus of glass sand was 2.40, within ASTM C33 limits of 2.3 to 3.1. Natural sand FM was 3.1. Glass fine aggregate conforms to ASTM C33 grading requirements and is suitable as fine aggregate replacement. Lower FM indicates finer particles and larger surface area, which can improve interfacial transition zone in concrete [13;25].

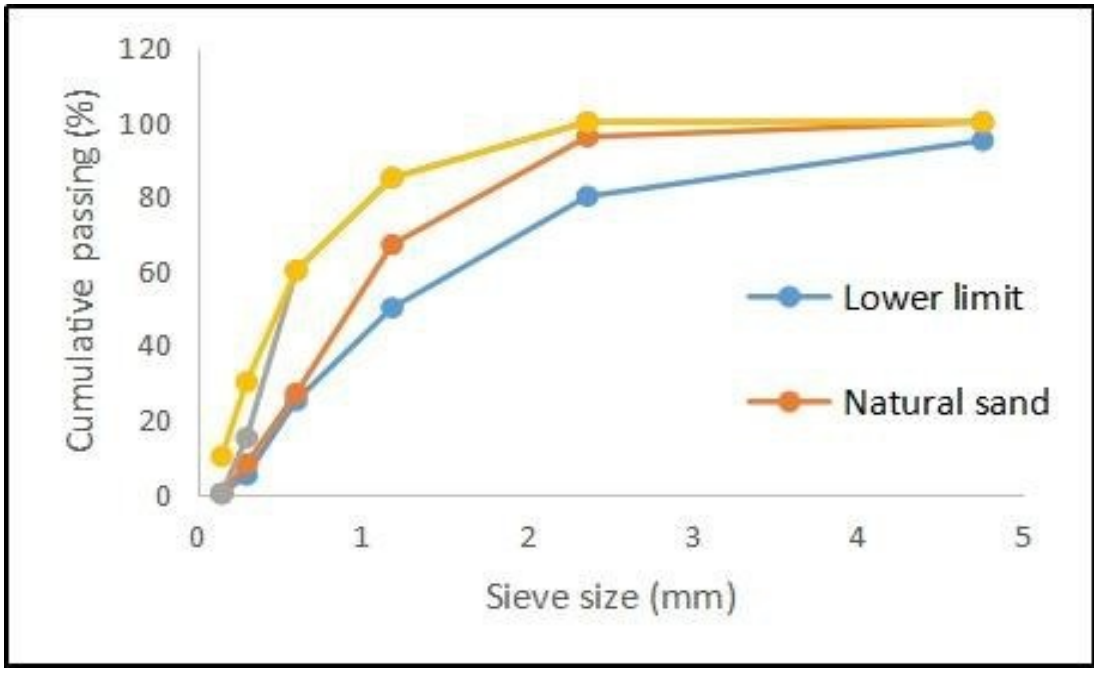


Fig. 6: Sieve analysis of glass fine aggregate vs natural sand

Conclusion

Waste glass processed to pass 45 µm meets ASTM C618 Class F requirements with $SiO_2+Al_2O_3+Fe_2O_3$ = 70.72%. SAI of 91% at 28 days and 49% $Ca(OH)_2$ consumption confirm pozzolanic activity. Crushed glass sieved to ASTM C33 grading with FM = 2.40 is suitable as fine aggregate replacement. Results demonstrate waste glass can be utilized for dual application as cement replacement and fine aggregate in sustainable concrete.

Reference

United Nations Environment Programme, 2019. _Sand and sustainability: Finding new solutions for environmental governance of global sand resources_. UNEP, Geneva.

United States Environmental Protection Agency, 2017. Facts and figures on materials, waste and recycling. https://www.epa.gov/facts-and-figures-about-materials-waste-and-recycling/national-overview-facts-and-figures-materials

Lopez, R.; El-Fata, C. (2024). Environmental Implications of Using Waste Glass as Aggregate in Concrete. Journal of Composite Science, 8(507), pp.1-19 https:// doi.org/10.3390/jcs8120507

Volaity, S.S., Aylas-Paredes, B.K., Han, T. et al. (2025). Towards decarbonization of cement industry: a critical review of electrification technologies for sustainable cement production. npj Material Sustainability **3**, 23(2025). https://doi.org/10.1038/s44296-025-00068-6

Tamanna, N. and Tuladhar, R., (2020). Sustainable Use of Recycled Glass Powder as Cement Replacement in Concrete. _Open Waste Management Journal_, 13, pp.1–13. https://doi.org/10.2174/1874347102013010001

Aliabdo, A.A., Elmoaty, A.E.M.A. and Aboshama, A.Y., (2016). Utilization of waste glass powder in the production of cement and concrete. _Construction and Building Materials_, 124, pp.866–877. https://doi.org/10.1016/j.conbuildmat.2016.08.016

Carsana, M., Frassoni, M. and Bertolini, L., 2014. Comparison of ground waste glass with other supplementary cementitious materials. _Cement and Concrete Composites_, 45, pp.39–45. https://doi.org/10.1016/j.cemconcomp.2013.09.005

Lee, H., Hanif, A., Usman, M., Sim, J. and Oh, H., 2018. Performance evaluation of concrete incorporating glass powder and glass sludge wastes as supplementary cementing material. _Journal of Cleaner Production_, 170, pp.683–693. https://doi.org/10.1016/j.jclepro.2017.09.133

Du, H. and Tan, K.H., (2017). Properties of high volume glass powder concrete. _Cement and Concrete Composites_, 75, pp.22–29. https://doi.org/10.1016/j.cemconcomp.2016.10.010

Gao, X., Yu, Q., Li, X.S. and Yuan, Y., 2020. Assessing the modification efficiency of waste glass powder in hydraulic construction materials. _Construction and Building Materials_, 263, 120111. https://doi.org/10.1016/j.conbuildmat.2020.120111

Ibrahim, S. and Meawad, A., 2018. Assessment of waste packaging glass bottles as supplementary cementitious materials. _Construction and Building Materials_, 182, pp.451–458. https://doi.org/10.1016/j.conbuildmat.2018.06.119

Kalakada, Z., Doh, J.H. and Chowdhury, S., 2019. Glass powder as replacement of cement for concrete–an investigative study. _European Journal of Environmental and Civil Engineering_, pp.1–18. https://doi.org/10.1080/19648189.2019.1695149

ASTM C33/C33M-18, 2018. Standard Specification for Concrete Aggregates. ASTM International, West Conshohocken, PA.

ASTM C150/C150M-20, 2020. Standard Specification for Portland Cement. ASTM International, West Conshohocken, PA.

ASTM C618-19, 2019. Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete. ASTM International, West Conshohocken, PA.

ASTM C311/C311M-22, 2022. Standard Test Methods for Sampling and Testing Fly Ash or Natural Pozzolans for Use in Portland-Cement Concrete. ASTM International, West Conshohocken, PA.

ASTM C39/C39M-21, 2021. Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens. ASTM International, West Conshohocken, PA.

Du, H., Tan, K. H., (2014). Waste glass powder as cement replacement in concrete, Journal of Advance Concrete Technology, 12(11), pp. 468–477, doi: 10.3151/jact.12.468.

Kim, T., & Olek, J. (2012). Effects of sample preparation and interpretation of thermogravimetric curves on calcium hydroxide in hydrated pastes and mortars. Transportation research record, 2290(1), 10-18.

Manullang, R.J., Samadhi, T.W. and Purbasari, A., 2017. Formulation of portland composite cement using waste glass as a supplementary cementitious material. _AIP Conference Proceedings_, 1855, 020040. https://doi.org/10.1063/1.5003523

García Del Toro, E.M. and Más López, M.I., (2018). Study of new formations of C-S-H in manufactured mortar with glass powder as binder. _Ingeniería e Investigación_, 38(3), pp.24–32. https://doi.org/10.15446/ing.investig.v38n3.67270

Wu, J., Liao, H., Ma, Z., Song, H., & Cheng, F. (2023). Effect of Different Initial CaO/SiO_2 Molar Ratios and Curing Times on the Preparation and Formation Mechanism of Calcium Silicate Hydrate. *Materials*, *16*(2), 717. https://doi.org/10.3390/ma16020717

Poudel, S., Bhetuwal, U., Kharel, P., Khatiwada, S., KC, D., Dhital, S., Lamichhane, B., Yadav, S. K., Suman, S., (2025). Waste Glass as Partial Cement Replacement in Sustainable Concrete: Mechanical and Fresh Properties Review. *Buildings*, *15*(6), 857. https://doi.org/10.3390/buildings15060857

Lam W. L., Cai, Y., Sun, K., Shen, P., (2024). Roles of ultra-fine waste glass powder in early hydration of Portland 2 cement: Hydration kinetics, mechanical performance, and microstructure. Construction and building materials. 415 (2024) https://doi.org/10.1016/j.conbuildmat.2024.135042

Korouzhdeh, T., Eskandari-Naddaf, H. & Kazemi, R. The ITZ microstructure, thickness, porosity and its relation with compressive and flexural strength of cement mortar; influence of cement fineness and water/cement ratio. *Frontiers of Structural and Civil Engineering* **16**, 191–201 (2022). https://doi.org/10.1007/s11709-021-0792-y