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Mechanical properties of eco-friendly cements-based glass powder in aggressive medium

Ibrahim Almeshal [a,b], Mustafa M. Al-Tayeb [c], Shaker M.A. Qaidi [d], B.H. Abu Bakar [b], Bassam A. Tayeh [a,*]

[a] Civil Engineering Department, Faculty of Engineering, Islamic University of Gaza, Gaza Strip P.O. Box 108, Palestine
[b] School of Civil Engineering, Engineering Campus, Universiti Sains Malaysia, 14300 Nibong Tebal, Pulau Pinang, Malaysia
[c] School College of Applied Engineering and Urban Planning, University of Palestine, Gaza, Palestine
[d] Department of Civil Engineering, College of Engineering, University of Duhok, Duhok, Kurdistan Region, Iraq

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ABSTRACT

Recycling glass waste for developing sustainable cementitious mortar and concrete have recently attracted increasing attentions for the construction industry. From another aspect, the nitrate-based environment due to chemical fertilizers has a significant effect on reinforced concrete and normal concrete by producing damages like its microstructure, corrosion of reinforcement. The major goal of this research work is to study the effect of Ammonium Nitrate (NH_4NO_3) on the unite weight and strength of glass mortar by performing experimental tests. In this article, eco-friendly mortar containing recycled glass powder (GP), as a replacement to cement, is submerged in NH_4NO_3 solutions. In total, 60 cement mortar mixtures were proportioned in this research work used GP passing sieves 200 µm. NH_4NO_3 solutions with 5, 10, and 20% concentration, and three different exposure periods 10, 30, and 60 days were applied. The experimental results showed that the effect of NH_4NO_3 on the density of mortar containing GP is less critical than that of conventional mortar. After 60 days of immersion in the solution with a concentration of 20% NH_4NO_3, the reduction in density of glassy mortar is less than that of ordinary mortar. Furthermore, the results indicated that the maximum compressive strength was attained at 10% replacement level of cement with GP by approximately 60 MPa after 60 days of immersion in NH_4NO_3 solution.

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1. Introduction

The production of cement is involved in energy consumption and produces an enormous amount of carbon dioxide, which has a greenhouse effect. Using supplementary cementitious material and waste materials is an effective method to reduce the cement industry's cost and carbon dioxide emission [1–3]. Therefore, sustainable concrete is urgently needed for building and construction. Nowadays, the Glass Powder (GP) modified the mechanical properties concrete is getting more popular because of cheaper rate and easy availability especially for construction building [4–8]. Generally, about 15–20% replacement of OPC with GP gives better mechanical properties results such as the compressive strength [5,6,9–12].

Therefore, utilizing GP as a cement replacement would produce a cleaner environment. There is a growing interest in the idea of eco-friendly concrete in some storage tanks within the agricultural industry exposed to silage cause deterioration of concrete due to containing lactic, and acetic acid has a pH value of approximately 4 [13–15]. There are series of chemical reactions occur between the nitrate solution and hydrated cement past [16–22]. Interestingly, several studies have shown the adverse effects of nitrate compounds [21,23–29].

GP has been used by several researchers in conventional concrete [30–33], geopolymer concrete [34–36], and cementitious environment [18,37,38]. This study investigates the use of GP as cement replacement material leaching in nitrate solutions and considers their effects on the physical and mechanical properties of the resulting mortar. Mortar, instead of concrete, was considered in this study because of the straightforward nature of the material behaviour, which can better indicate the effects of the studied materials. For instance, experimental tests on mortar are more

* Corresponding author.
E-mail address: btayeh@iugaza.edu.ps (B.A. Tayeh).

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controllable than those on concrete [39]. Most conclusions drawn from the observations on mortar in this study can be transferable to concrete, which has coarse aggregates as an additional phase [40].

2. Research significance

The storage of chemical fertilizers in concrete buildings often leads to durability problems due to chemical attacks. The damage of concrete is mostly caused by certain ammonium salts. Few studies have examined the effect of ammonium nitrate on concretes properties after long periods of exposure. The objective of this research was to observe the effect of ammonium nitrate on properties of cement mortar contained glass powder passing sieve 200 μm.

3. Experimental program

3.1. Materials used

Ordinary Portland cement CEM I 52.5 N obtained from Arish, Egypt was used in this study, the physical and chemical properties were satisfied to the requirements of ASTM C 150 specifications, the physical and chemical properties of cement are summarized in Table 1. The recycled glass powder GP used in this study, was obtained by crushing recycled glass which passing sieves 200 μm. The physical and chemical properties of GP are summarized in Table 1; Fig. 1. shows the preparation procedure used to obtain GP (see Figs. 2,3).

Locally available river sand was used as natural fine aggregate in saturated surface-dry condition; Table 2 shows the grading size distribution of fine aggregate, the specific gravity and water absorption of the fine aggregates are typically 2.6 and 0.57%, respectively, and the maximum sieve size for the fine aggregate is 600 μm were determined in accordance with ASTM C128. The samples were placed in NH_4NO_3 solutions with different concentration 5%, 10%, and 20%.

Table 1
Physical properties and oxide compositions of cement and GP.

Property	OPC	GP
Specific gravity	3.15	2.33
Fineness, cm^2/gm	3460	3319
Loss on ignition, %	0.9	–
CaO, %	65	11
SiO_2, %	20.6	68
Al_2O_3, %	4.6	7
Fe_2O_3, %	2.7	1
MgO, %	2.4	1
SO_3, %	2.1	0.4
NaO_2, %	0.13	12
K_2O_2 %	0.49	1

3.2. Mixture proportions and specimen preparation

The mixture proportion of the cement:sand was 1:3 with constant w/c 0.4. Replacement of GP was varied from 0 to 30% with the mass of cement. Mixture proportioning was done for the M50 grade of mortar with a target cube strength of 60 MPa; details are presented in Table 3. In total, 60 cement mortar mixtures were proportioned in this research work used GP passing sieves 200 μm. In each mixture, nine 50 mm cube specimens, in total, 340 cement mortar cube specimens were cast to study the unit weight, water absorption, and compressive strength of cement mortar at various ages 7, 28, and 60 days. Then they were stored in the solution NH_4NO_3 with 5%, 10%, and 20% concentration for several periods 10 days, 30 days, and 60 days. The eight cement mortar mixtures conducted in this study were made by varying the following parameters:

a) Percentage of replacement with GP;
b) Concentration of the solution NH_4NO_3;
c) Period of immerse in NH_4NO_3 solution;
d) Curing age.

4. Results and discussions

4.1. Unit weight

The unit weight was measured according to ASTM C 150-21 [41]. The detailed results for unit weight are given in Figs. 4–6 and Table 4. The obtained results indicate that the glassy mortar

Fig. 1. Preparation of GP.

Fig. 2. Preparing Ammonium Nitrate solutions.

Fig. 3. Specimens exposed to NH_4NO_3 solutions.

Table 2
Grading size distribution of sand.

Sieve No.	Sieve Opening (mm)	Percentage of Passing (%)
#30	0.6	98
#40	0.4	70
#50	0.3	25
#100	0.15	0

Table 3
Mixture proportions of all mixtures (kg/m^3).

Mixture ID	cement OPC	GP	sand	water	w/c
CTL-1	500	–	800	200	0.4
MI-10	450	50	800	200	0.4
MI-20	400	100	800	200	0.4
MI-30	350	150	800	200	0.4

densities decrease with the increase in GP% and with the increase in the concentration of NH_4NO_3 with time. The capillary system in cement paste increases significantly due to leaching of NH_4NO_3 solutions with a concentration of 20% immersed for 60 days as shown in Fig. 6. However, the permeability mortars containing GP was decreased at a later age and that is different from than CTL-1 mix. That behaviour could be attributed to the increase of calcium-silicate-hydrate (C-S-H) due to ultra-fine GP. Therefore, the hydrated C-S-H fills the pores and resulting in a mortar with low porosity [4,6,7,10,42].

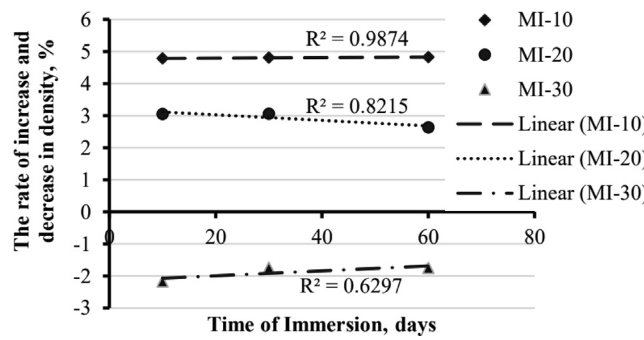

Fig. 4. The comparison of density variation with time for 5% NH_4NO_3 solution.

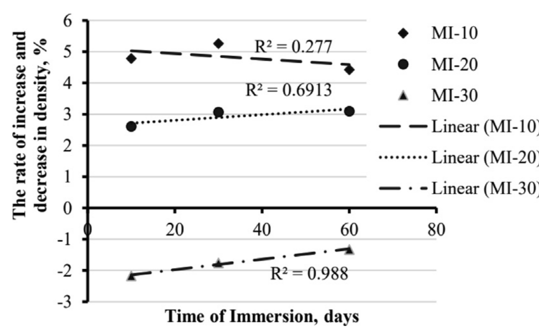

Fig. 5. The comparison of density variation with time for 10% NH_4NO_3 solution.

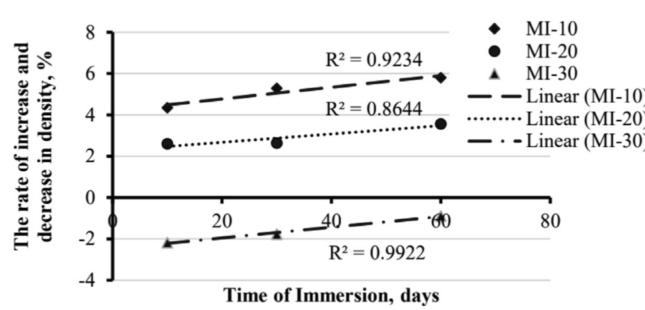

Fig. 6. The comparison of density variation with time for 20% NH_4NO_3 solution.

Ismail and Al-Hashmi [43] reported that the fresh density of cementitious composites mixtures decreased by 1.26%, 1.96% and 2.26% with the inclusion of 10%, 15% and 20% waste glass (size

Table 4
Effect of Concentration of NH_4NO_3 on unit weight on GM mixtures.

Mixture ID	Time of Immersion, days	Unit weight, gm/cm^3		
		Concentration of NH_4NO_3		
		5%	10%	20%
CTL-1	10	2.3	2.3	2.3
	30	2.29	2.28	2.27
	60	2.28	2.26	2.24
MI-10	10	2.41	2.41	2.4
	30	2.4	2.4	2.39
	60	2.39	2.38	2.37
MI-20	10	2.37	2.36	2.36
	30	2.36	2.35	2.33
	60	2.34	2.33	2.32
MI-30	10	2.25	2.25	2.25
	30	2.25	2.24	2.23
	60	2.24	2.23	2.22

Table 5
Effect NH_4NO_3 on compressive strength of GM mixtures.

Mixture ID	Time of Immersion, days	Compressive strength, MPa		
		Concentration of NH_4NO_3		
		5%	10%	20%
CTL-1	10	61	59	56
	30	56	54	49
	60	52	49	44
MI-10	10	60	60	58
	30	59	58	54
	60	55	55	51
MI-20	10	53	53	51
	30	52	48	47
	60	49	48	45
MI-30	10	51	51	48
	30	50	46	44
	60	46	44	42

4.75–0.15 mm) as replacement, by weight. Batayneh et al. [12] reported a reduction in the fresh unit weight of concrete mixtures containing crushed waste glass (close to lower limit of the specified fine aggregate limits according to BS 882:1992). The reduction in the fresh unit weight was 0.24%, 0.15%, 0.71% and 0.84% with the inclusion of 5%, 10%, 15% and 20% glass, respectively. From the previous literature, it can be noted that the inclusion of GP decreases the density. This reduction in the density can be attributed to the lower specific gravity and the lower density of GP compared to cement [44].

4.2. Compressive strength

The effect of various parameters, such as replacement of GP, and age, with the different concentrations of NH_4NO_3 solution, on compressive strength, are discussed in this section. The reduction in compressive strength of glassy mortars was found to be decreased with an increase in replacement of cement with GP. The maximum compressive strength was attained at 10% replacement level of cement with GP by approximately 60 MPa and reference mix was 61 MPa. It can also be inferred those small particles of GP improved the particle packing and, hence, enhanced the compressive strength in cement mortar exposed to NH_4NO_3 solution. Table 5 and Figs. 7–9 show that the compressive strength of glassy mortar decreased with an increase in the concentration of NH_4NO_3 solution. When cement was 20% replaced with GP, compressive strength of mortar was comparably equal or marginally less than

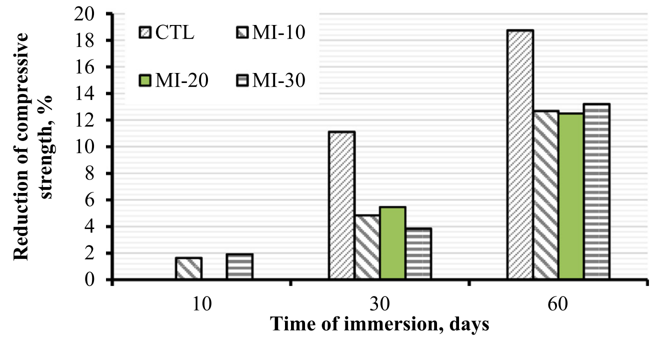

Fig. 7. Percentage of reduction for compressive strength exposed to 5% NH_4NO_3 solution.

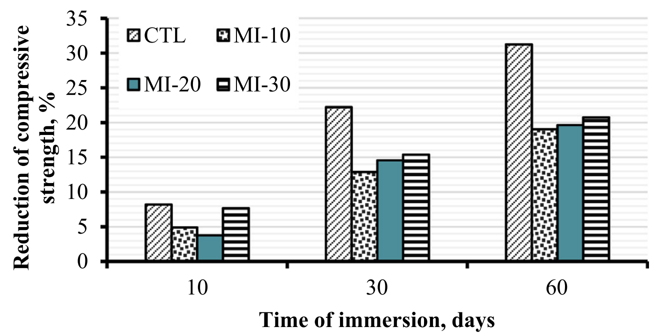

Fig. 8. Percentage of reduction for compressive strength exposed to 10% NH_4NO_3 solution.

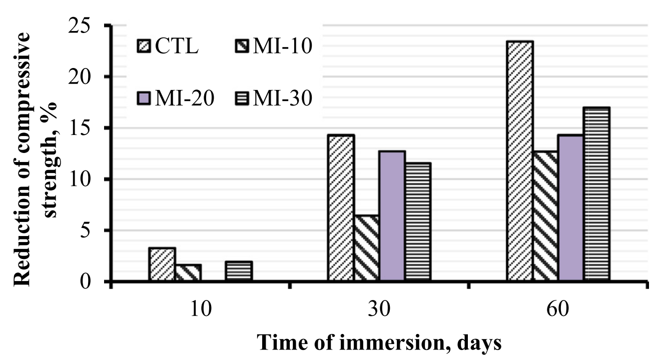

Fig. 9. Percentage of reduction for compressive strength exposed to 20% NH_4NO_3 solution.

reference mortar mixtures, depending on concentrations of NH_4NO_3 solution. The compressive strength decreased at long ages which could be attributed to anionic forms of silicate and late polymerization. The resulting pH level was not conducive to stable molecular forms and it was more difficult to form the coagulated structure, thus resulting in lower rates of polymer formation.

In general, replacing cement by GP was improved the compressive strength of cement mortars with substitution level up to 20%. The results agree with the earlier field investigation by Nassar and Soroushian (2011) and Islam et al., [45,46]. Review by Rashed (2014) indicated that overall there is a contradiction; some reported strength increment while other reported decrease in strength [44] in mortar.

5. Conclusion

Based on the test results, the following conclusions are drawn:

1. Using GP as a replacement to cement led to increase the global density of mortar samples. At 10% and 20% replacement level, the density increased by 3% and 4.8%.
2. The unit weight of all mortar samples including glassy mortars was decreased with increasing the concentration rate of NH_4NO_3, this reduction in unit weight could be attributed to the decomposition of some components of mortar.
3. The compressive strength of mortar samples containing GP was improved with increasing the replacement level up to 20%. In 20% NH_4NO_3 solution and after 60 days, the reduction percentages of compressive strength for reference mix, MI-10 and MI-20 were 27.8%, 16.3%, and 26.2%.
4. Replacement of cement with 20 % GP can be practiced for the production of glassy mortar because there is a comparable achievement of strength with the reference mixture.
5. GP mortars compared with control mixes had a good behaviour in external exposure curing with the NH_4NO_3 solution (specifically, a residual strength) due to its 10% replacement with GP.

CRediT authorship contribution statement

Ibrahim Almeshal: Investigation, Methodology, Formal analysis, Conceptualization. **Mustafa M. Al-Tayeb:** Writing - original draft, Formal analysis. **Shaker M. A. Qaidi:** Writing - original draft, Formal analysis. **B.H. Abu Bakar:** Writing - review and editing. **Bassam A. Tayeh:** Supervisor, Conceptualization, Validation, Review peting financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

[1] J. Duchesne, M.A. Bérubé, Effect of supplementary cementing materials on the composition of cement hydration products, Adv. Cem. Based Mater. 2 (2) (1995) 43–52.
[2] B.A. Tayeh, D.M. Al Saffar, A.S. Aadi, I. Almeshal, Sulphate resistance of cement mortar contains glass powder, J. King Saud Univ. – Eng. Sci. 32 (8) (2020) 495–500.
[3] B.A. Tayeh, I. Almeshal, H.M. Magbool, H. Alabduljabbar, R. Alyousef, Performance of sustainable concrete containing different types of recycled plastic, J. Clean. Prod. 328 (2021) 129517, https://doi.org/10.1016/j.jclepro.2021.129517.
[4] A.I. Jubeh, D.M. Al Saffar, B.A. Tayeh, Effect of recycled glass powder on properties of cementitious materials contains styrene butadiene rubber, Arab J Geosci. 12 (2) (2019), https://doi.org/10.1007/s12517-018-4212-0.
[5] D.-M.-A.-R. Al Saffar, Experimental investigation of using ultra-fine glass powder in concrete, Int. J. Eng. Res. Appl. 7 (9) (2017) 33–39.
[6] B.A. Tayeh, Effects of marble, timber, and glass powder as partial replacements for cement, J. Civ. Eng. Constr. 7 (2) (2018) 63–71.
[7] M. Mousa, E. Cuenca, L. Ferrara, N. Roy, A. Tagnit-Hamou, "Tensile Characterization of an 'Eco-Friendly' UHPFRC with waste glass powder and glass sand," 2018, pp. 238–248.
[8] H. Ez-zaki, B. El Gharbi, A. Diouri, Development of eco-friendly mortars incorporating glass and shell powders, Constr. Build. Mater. 159 (Jan. 2018) 198–204, https://doi.org/10.1016/j.conbuildmat.2017.10.125.
[9] H.-Y. Wang, W.-L. Huang, Durability of self-consolidating concrete using waste LCD glass, Constr. Build. Mater. 24 (6) (Jun. 2010) 1008–1013, https://doi.org/10.1016/j.conbuildmat.2009.11.018.
[10] B. Taha, G. Nounu, Properties of concrete contains mixed colour waste recycled glass as sand and cement replacement, Constr. Build. Mater. 22 (5) (May 2008) 713–720, https://doi.org/10.1016/j.conbuildmat.2007.01.019.
[11] M.C. Limbachiya, Bulk engineering and durability properties of washed glass sand concrete, Constr. Build. Mater. 23 (2) (Feb. 2009) 1078–1083, https://doi.org/10.1016/j.conbuildmat.2008.05.022.
[12] M. Batayneh, I. Marie, I. Asi, Use of selected waste materials in concrete mixes, Waste Manage. 27 (12) (Jan. 2007) 1870–1876, https://doi.org/10.1016/j.wasman.2006.07.026.
[13] V. Zivica, A. Bajza, Acidic attack of cement based materials — a review, Constr. Build. Mater. 15 (8) (Dec. 2001) 331–340, https://doi.org/10.1016/S0950-0618(01)00012-5.
[14] C. O'Donnell, V.A. Dodd, P. O'Kiely, M. Richardson, A study of the effects of silage effluent on concrete: Part 1, Significance of concrete characteristics, J. Agric. Eng. Res. 60 (2) (Feb. 1995) 83–92, https://doi.org/10.1006/jaer.1995.1002.
[15] E. Gruyaert, P. Van den Heede, M. Maes, N. De Belie, Investigation of the influence of blast-furnace slag on the resistance of concrete against organic acid or sulphate attack by means of accelerated degradation tests, Cem. Concr. Res. 42 (1) (Jan. 2012) 173–185, https://doi.org/10.1016/j.cemconres.2011.09.009.
[16] S. Larreur-Cayol, A. Bertron, G. Escadeillas, Degradation of cement-based materials by various organic acids in agro-industrial waste-waters, Cem. Concr. Res. 41 (8) (Aug. 2011) 882–892, https://doi.org/10.1016/j.cemconres.2011.04.007.
[17] T.A. Aiken, W. Sha, J. Kwasny, M.N. Soutsos, Resistance of geopolymer and Portland cement based systems to silage effluent attack, Cem. Concr. Res. 92 (Feb. 2017) 56–65, https://doi.org/10.1016/j.cemconres.2016.11.015.
[18] N. Durban, Y. Rafrafi, A. Rizoulis, A. Albrecht, J.-C. Robinet, J.R. Lloyd, A. Bertron, B. Erable, Nitrate and nitrite reduction at high pH in a cementitious environment by a microbial microcosm, Int. Biodeterior. Biodegradation 134 (2018) 93–102, https://doi.org/10.1016/j.ibiod.2018.08.009.
[19] S. Tasnim, M.E. Rahman, R.B. Ahmadi, Mechanical performance of modified cement paste made with micro-fine POFA in ammonium nitrate environment, Constr. Build. Mater. 162 (Feb. 2018) 534–542, https://doi.org/10.1016/j.conbuildmat.2017.12.060.
[20] J. Arnold, R. Duddu, K. Brown, D.S. Kosson, Influence of multi-species solute transport on modeling of hydrated Portland cement leaching in strong nitrate solutions, Cem. Concr. Res. 100 (Oct. 2017) 227–244, https://doi.org/10.1016/j.cemconres.2017.06.002.
[21] M.J. Millard, K.E. Kurtis, Effects of lithium nitrate admixture on early-age cement hydration, Cem. Concr. Res. 38 (4) (Apr. 2008) 500–510, https://doi.org/10.1016/j.cemconres.2007.11.009.
[22] Q.T. Phung, D. Jacques, N. Maes, J. Perko, G. Ye, G. De Schutter, Modelling decalcification of cement paste in ammonium nitrate solution, in: 3rd International Conference on Service Life Design for Infrastructure: Keynote Speech, 2014, pp. 27–40.
[23] W.J. McCoy, A.G. Caldwell, New Approach to inhibiting alkali-aggregate expansion, ACI J. Proc. 4 (5) (1951), https://doi.org/10.14359/12030.
[24] D.P. Bentz, Lithium, potassium and sodium additions to cement pastes, Adv. Cem. Res. 18 (2) (2006) 65–70.
[25] D.P. Bentz, P.E. Stutzman, Curing, hydration, and microstructure of cement paste, ACI Mater. J., 103(5) (2006), doi: https://doi.org/10.14359/18157.
[26] I. Odler, H. Dörr, Early hydration of tricalcium silicate II. The induction period, Cem. Concr. Res. 9 (3) (May 1979) 277–284, https://doi.org/10.1016/0008-8846(79)90119-4.
[27] M. C. G. Juenger, H.M. Jennings, Effects of high alkalinity on cement pastes, ACI Mater. J., 98(3) (2001), doi: https://doi.org/10.14359/10280.
[28] D.S. Lane, V.C.T. Board, Laboratory investigation of lithium-bearing compounds for use in concrete, Virginia Transport. Res. Council (2002).
[29] S. Igarashi, A. Watanabe, M. Kawamura, Evaluation of capillary pore size characteristics in high-strength concrete at early ages, Cem. Concr. Res. 35 (3) (Mar. 2005) 513–519, https://doi.org/10.1016/j.cemconres.2004.06.036.
[30] D.A. Kulik, Improving the structural consistency of C-S-H solid solution thermodynamic models, Cem. Concr. Res. 41 (5) (May 2011) 477–495, https://doi.org/10.1016/j.cemconres.2011.01.012.
[31] C. Glass, J. Silverstein, Denitrification kinetics of high nitrate concentration water: pH effect on inhibition and nitrite accumulation, Water Res. 32 (3) (Mar. 1998) 831–839, https://doi.org/10.1016/S0043-1354(97)00260-1.
[32] C. Glass, J. Silverstein, Denitrification of high-nitrate, high-salinity wastewater, Water Res. 33 (1) (Jan. 1999) 223–229, https://doi.org/10.1016/S0043-1354(98)00177-8.
[33] L. De Windt, A. Bertron, S. Larreur-Cayol, G. Escadeillas, Interactions between hydrated cement paste and organic acids: Thermodynamic data and speciation modeling, Cem. Concr. Res. 69 (Mar. 2015) 25–36, https://doi.org/10.1016/j.cemconres.2014.12.001.
[34] A. Palomo, M.T. Blanco-Varela, M.L. Granizo, F. Puertas, T. Vazquez, M.W. Grutzeck, Chemical stability of cementitious materials based on metakaolin, Cem. Concr. Res. 29 (7) (Jul. 1999) 997–1004, https://doi.org/10.1016/S0008-8846(99)00074-5.
[35] T. Bakharev, Resistance of geopolymer materials to acid attack, Cem. Concr. Res. 35 (4) (Apr. 2005) 658–670, https://doi.org/10.1016/j.cemconres.2004.06.005.
[36] A.M.M. Al Bakri, H. Kamarudin, M. Bnhussain, I.K. Nizar, A.R. Rafiza, Y. Zarina, The processing, characterization, and properties of fly ash based geopolymer concrete, Rev. Adv. Mater. Sci 30 (1) (2012) 90–97.
[37] L. Truche, G. Berger, A. Albrecht, L. Domergue, Abiotic nitrate reduction induced by carbon steel and hydrogen: implications for environmental processes in waste repositories, Appl. Geochem. 28 (Jan. 2013) 155–163, https://doi.org/10.1016/j.apgeochem.2012.10.010.
[38] Y. Rafrafi, H. Ranaivomanana, A. Bertron, A. Albrecht, B. Erable, Surface and bacterial reduction of nitrate at alkaline pH: Conditions comparable to a nuclear waste repository, Int. Biodeterior. Biodegradation 101 (Jul. 2015) 12–22, https://doi.org/10.1016/j.ibiod.2015.03.013.
[39] A.M. Rashad, A synopsis about the effect of nano-Al2O3, nano-Fe2O3, nano-Fe3O4 and nano-clay on some properties of cementitious materials – A short guide for Civil Engineer, Mater. Des. 52 (Dec. 2013) 143–157, https://doi.org/10.1016/j.matdes.2013.05.035.
[40] E. Mohseni, M.A. Yazdi, B.M. Miyandehi, M. Zadshir, M.M. Ranjbar, Combined effects of Metakaolin, rice husk ash, and polypropylene fiber on the

engineering properties and microstructure of mortar, J. Mater. Civ. Eng. 29 (7) (Jul. 2017) 04017025, https://doi.org/10.1061/(ASCE)MT.1943-5533.0001867.
[41] ASTM C150 / C150M-21, "Standard Specification for Portland Cement." ASTM International, West Conshohocken, PA, 2021, doi: https://doi.org/10.1520/C0150_C0150M-21.
[42] H. Elaqra, R. Rustom, Effect of using glass powder as cement replacement on rheological and mechanical properties of cement paste, Constr. Build. Mater. 179 (Aug. 2018) 326–335, https://doi.org/10.1016/j.conbuildmat.2018.05.263.
[43] Z.Z. Ismail, E.A. AL-Hashmi, Recycling of waste glass as a partial replacement for fine aggregate in concrete, Waste Manage. 29 (2) (2009) 655–659.
[44] A.M. Rashad, Recycled waste glass as fine aggregate replacement in cementitious materials based on Portland cement, Constr. Build. Mater. 72 (Dec. 2014) 340–357, https://doi.org/10.1016/j.conbuildmat.2014.08.092.
[45] G.M.S. Islam, M.H. Rahman, N. Kazi, Waste glass powder as partial replacement of cement for sustainable concrete practice, Int. J. Sustain. Built Environ. 6 (1) (Jun. 2017) 37–44, https://doi.org/10.1016/j.ijsbe.2016.10.005.
[46] R.-U.-D. Nassar, P. Soroushian, Field investigation of concrete incorporating milled waste glass, J. Solid Waste Technol. Manag. 37 (4) (Nov. 2011) 307–319, https://doi.org/10.5276/JSWTM.2011.307.