Alkali-Silica. Reaction Of Foamed. Concrete Containing. Waste Glass as Aggregate

Nawal B Massekh¹, Dr. Ameer A. Hillal²

¹,²Civil Engineering Department/ College of Engineering/ University of Anbar /Iraq
¹naw19e1012@uoanbar.edu.iq,²Ameer.Hilal@uoanbar.edu.iq

Abstract. This research focused on examining Alkali-Silica Reaction (ASR) of foamed concrete mixes containing different types of crushed waste glass (CWG) with different chemical compositions. The reactivity was determined in sodium hydroxide solution by adopting mortar bar test. Four types of waste glass with different particle sizes and different percentages content were used. From the test results of recorded expansion of these mixes, it was noticed that the coarse glass resulted in more expansion than that of fine glass. Lead-silicate glass (CR) exhibits the maximum expansion followed by soda-lime glass (SL) and boro-silicate glass (BS), while less expansion was recorded in mixes with green glass (GG). As compared to reference mix (FC), it was noted that the mixes with crushed waste glass (SL), (BS), and (CR) undergo notable expansion, while the expansion of the mixes with (GG) slightly increased compared to the reference mix (FC).

1. Introduction

Foamed concrete is a special type of lightweight concrete. It has been paid much more attention due to low energy consumption. The percentage of its air content is more than 20% by volume [1]. Its density ranges between 300 and 1850 kg/m³, while its compressive strength ranges from 1 to 25 MPa at 28 days. It is firstly recognized by Romans [2]. It mainly consists of cement, water, fine sand and foam. Foaming agent is the determinant of density by the air babbles formed in cement paste [3]. It must be noted that the cells of foam must have sufficient stability to prevent separation between air bubbles and cement paste and to ensure that cells do not break down. Air cells size ought to be ranges between 0.1 and 1 mm to ensure homogenous of structure [4]. Foamed concrete has become a trend in use due to the good thermal insulation, excellent sound absorption (approximately 10-times greater than normal concrete), excellent seismic resistance, good resistance to fire, with very low pollution and sufficient strength to fit the requirements of construction [5,6,7,8]. It was reported that no need for vibration and compaction during its production [2]. It is widely used in many applications such as sub base in highways, void filling, insulation floor screeds, cast-in-situ, sunken portion filling, embankments, precast blocks, trench backfill and prefabricated insulation boards [9]. Waste glass represents the largest proportion of solid wastes. It occupies approximately 1.8 billion tons per year of total solid waste [10]. In addition, it is non-biodegradable, i.e. a big problem for stockpiling landfiling and environment concerns [11]. Glass is a unique substance material. It is 100% recyclable that can create to a new form without loss of its chemical composition [12,13,14]. It has been examined as construction material since 1960s [15,16]. Glass is too close to sand nature. Studies concluded that glass can be used as coarse aggregate, fine aggregate and powder [13]. Using crushed glass brings many benefits such as preserving natural resources, decreasing energy requirements for manufactures process and decreasing CO₂ emission [17].
However, using coarse and fine crushed glass causes the phenomenon of Alkali-Silica Reaction (ASR), while using glass powder can reduce it [13]. ASR considered as one of the most damaging events to concrete [18]. Therefore, this research is significant from two sides. First, from environmental point of view by using waste material in producing foamed concrete. Second, from durability point of view by examining the deterioration which caused by Alkali-Silica Reaction in foamed concrete made with waste glass as aggregate. The aim of this research is to investigate to what extent utilization of different types of waste glass (i.e. different chemical composition), as partial replacement of sand (coarse and fine aggregate) causes deleterious Alkali-Silica Reaction (ASR) in foamed concrete mixes.

2. Details of experimental work

2.1. Materials

2.1.1 Cement:

Ordinary Portland cement (Type I) from AL-MASS Company was used to produce investigated foamed concrete mixes. The cement used was confirmed to ASTM C 150 [20].

2.1.2 Sand:

Natural river sand was used in the experimental work with maximum size of 2.36 mm, the grain size distribution was according to ASTM C 33[21].

2.1.3 Foam:

A protein foaming agent was used. In order to produce 1 liter of foam, 1g of foaming agent was diluted in 40 g of water. The solution then put in foam generator and compressed with air at 8 psi to gain stable foam of 30 kg/m3 density.

2.1.4 Tap water

was used to produce foamed concrete mixes.

2.1.5 Glass:

four types of waste glass was used as soda-lime glass (SL), coming from sheet window glass, Borosilicate glass (BS), collected from pharmaceutical containers, green-glass (GG) collected from soda drink containers and lead-silicate glass (CR) collected from neon tubing. Noted that all these glass types were collected from local recycling stream. Chemical compositions of all selected types of glass are shown in ‘table 1’. The investigated glass was immersed in water for about 24 hours to remove labels and impurities, then dried in air and crushed to required sizes and quantities according to ASTM C1260 [22]. ‘figure 1’ illustrates types of glass used after crushing. Specific gravities for SL, BS, GG and CR were 2.46, 2.59, 2.5, 2.52 respectively, which were determined according to ASTM C 128 [23], while its bulk density is1360 kg/m3[24].
Figure 1. Types of glass used: (a) green glass (b) soda-lime glass (c) lead-silicate glass (d) boro-silicate glass.

Table 1. Chemical composition of glass used.

| Chemical glass composition | Soda-lime glass | Boro-silicate glass | Green glass | Lead–silicate glass |
|----------------------------|-----------------|---------------------|-------------|---------------------|
| Na$_2$O                    | 12.87           | 11.29               | 8.05        | 11.07               |
| MgO                        | 4.03            | 0.64                | 0.78        | 3.41                |
| Al$_2$O$_3$                | 0.65            | 2.16                | 2.05        | 3.57                |
| SiO$_2$                    | 72.27           | 65.25               | 67.21       | 67.35               |
| SiO$_3$                    | 0.14            | 0.00                | 0.38        | 2.72                |
| K$_2$O                    | 0.75            | 0.75                | 0.58        | 6.50                |
| CaO                        | 8.51            | 13.33               | 6.18        | 3.28                |
| TiO$_2$                    | 0.00            | 1.27                | 0.76        | 1.17                |
| Cr$_2$O$_3$                | 0.00            | 1.15                | 3.98        | 0.76                |
| Fe$_2$O$_3$                | 0.76            | 2.52                | 2.54        | 0.07                |
Crushed glass was used as partial replacement of sand volume. In addition to the reference mix (FC), four groups of foamed concrete mixes were produced for each type of waste glass as FCSL for soda-lime glass type, FCBS for boro-silicate glass type, FCGG for green glass type and FCCR for lead-silicate glass type. The replacement of sand was 50% fine glass (FC..1), 50% coarse glass (FC..2), and 25% fine glass with 25% coarse glass (FC..3) used to produce mixes which were denoted by FCSL-1, FCSL-2, FCBS-1, FCBS-2, FCBS-3, FCGG-1, FCGG-2, FCGG-3, FCCR-1, FCCR-2, FCCR-3. The mixes constituents was highlighted in ‘table 2’. All mixes of foamed concrete with density of 1200 ± 50 kg/m³ were prepared in a rotary mixer of 0.1 m³ volume. Cement, sand, crushed glass was firstly put and mixed for some minutes, then water was added gradually. After that a stable foam was prepared and added to the wet mixture. The mix was put in the molds with approximately two equal layers and a trowel was used for surface finishing. The specimens left in the molds for 24 hours then they were taken out and wrapped in a cling film to prevent moisture loss.

**Table 2. Mixes constituents.**

| Material | Cement (Kg/m³) | Sand (Kg/m³) | W/C | Foam (Liter/m³) | Fine glass (Kg/m³) | Coarse glass (Kg/m³) |
|----------|----------------|--------------|-----|-----------------|-------------------|---------------------|
| FC       | 400            | 604          | 0.49| 449             | -                 | -                   |
| FC-1     | 400            | 302          | 0.49| 449             | 283.6             | -                   |
| FC-2     | 400            | 302          | 0.49| 449             | -                 | 283.6               |
| FC-3     | 400            | 302          | 0.49| 449             | 141.8             | 141.8               |
| FCBS-1   | 400            | 302          | 0.49| 449             | 298.5             | -                   |
| FCBS-2   | 400            | 302          | 0.49| 449             | -                 | 298.5               |
| FCBS-3   | 400            | 302          | 0.49| 449             | 149.3             | 149.3               |
| FCGG-1   | 400            | 302          | 0.49| 449             | 288               | -                   |
| FCGG-2   | 400            | 302          | 0.49| 449             | -                 | 288                 |
| FCGG-3   | 400            | 302          | 0.49| 449             | 144               | 144                 |
| FCCR-1   | 400            | 302          | 0.49| 449             | 290.5             | -                   |
| FCCR-2   | 400            | 302          | 0.49| 449             | -                 | 290.5               |
| FCCR-3   | 400            | 302          | 0.49| 449             | 145.3             | 145.3               |
4. ASR mechanism

Chemical reaction that taking place during ASR process is complicated and incomprehensible to the present [25, 26]. It occurs between silica in aggregate and high alkaline in cement paste to create a new product that have the ability to stretch and cause an internal tensile stress. Ingredients from cement components Na\(^+\), K\(^+\), OH\(^-\), Ca\(^{2+}\) and SO\(_4^{2-}\) inter to the water while mixing process [27]. The first event is to break the network siloxane aggregate which occurs as a result of the hydroxyl\(^-\)ions aggression which leads to formation of silicate acid Si(OH)\(_4\) [28], as illustrates in equation (1).

\[
nSiO_2 + OH^- \rightarrow Si(OH)_4
\]

The alkalis cation are sucking towards the surface of dissolved silicate sort. Pilling up of these cations leads to appearance of double layer and soluble and gel at the end. The interaction is expressed in equation (2).

\[
rSiO_2 + mNa_2O + nK_2O + pCaO + qH_2O \rightarrow [(Na_2O)(K_2O)(CaO)p](SiO)_2.qH_2O
\]

(2)

Where: \(r, m, n, p\) and \(q\) the number of interacting molecules.

It is believed that three factors must be present for occurrence of Alkali-Silica Reaction: reactive aggregate, sufficient alkalis and presence of moisture [29, 30]. Meanwhile, concrete mixing, hydroxyl ion which in high concentrations strikes the surface of glass partial sharply. Noted that Na-O, Ca-O and K-O are very weak bonds as compared to Si-O. Sodium and potassium are dissolved firstly then the depolymerization of network silicate glass as illustrated in equation (3).

\[
Si - O - Si + 3OH^- \rightarrow [SiO(OH)_3]^-
\]

(3)

After that and when [SiO(OH)\(_3\)]\(^-\) become in attachment with Ca\(^{2+}\)and Na\(^+\), they unite to form the so-called N-C-S-H gel. Which settled on the external surfaces of glass particle, this reaction summarized in equation (4).

\[
Ca^{2+} + Na^+ [SiO(OH)_3]^- \rightarrow N - C - S - H
\]

(4)

5. ASR test

Mortar bar test according to ASTM C1260 [22] was adopted to investigate ASR and to evaluate to what extent using of crashed glass as aggregate affects foamed concrete. Prisms of (40x40x160) mm dimension were used for ASR test. After curing for 24 hour with cling film, zero length was recorded for each specimen by digital Vernier with 0.001mm accuracy. Then they soaked in 1NaOH solution which put in well closed polyethylene containers in 80±2 C˚. The change in length was recorded periodically and an average length of three prisms for each mix was taken. The test duration was 60 days in order to gain more reliable results.

6. Results

Figures 2, 3, 4 and 5 show the expansion behaviour of investigated foamed concrete mixes during 60 days immersion in 1NaOH solution at 80C˚the expansion increased progressively with time. For all investigated foamed concrete mixes with 50% replacement of natural sand by crushed waste glass, it was found that the finer the glass particle sizes the lower the expansion and this is agreed with [30, 32].
Whilst the expansion that recorded for mixes with 25% fine glass and 25% coarse glass was almost between the values of only fine and only course glass mixes. This can be attributed to the mechanism of ASR expansion which induced within the internal cracks of large crushed glass particles rather than at the glass-cement paste interface. From the results, it was observed that Lead-Silicate glass (CR) exhibits the maximum expansion as compared with the rest selected types of glass. This may due to the higher content of K$_2$O which is the weakest bond in addition to CaO and Na$_2$O bonds, see ‘Table [31]’. Noted that expansion is not directly related to the silica content in the glass used as aggregate. Soda-lime glass has the highest SiO$_2$ content but was not the higher in expansion and this agreed with Andrea [25]. Green class shows the lowest expansion, due to the presence of Cr$_2$O$_3$ [33], while the mixes expansion with boro-silicate glass was slightly more than that of mixes with green glass. It is easy to conclude that ASR reaction occurs in foamed concrete, however it is less expansion than that of mixes contained crushed waste glass. From test results it was noted that the mixes with crushed waste glass (CR), (SL), (BS) undergo notable expansion as compared to reference mix (FC), while the mixes with (GG) slightly increased as compared to the limits of (FC) mix. ‘figure 6’ illustrates ASR expansion for all mixes of foamed concrete after 60 days.

![Figure 2](image2.png)

**Figure 2.** Expansion curves of foamed concrete mixes with replacing sand by: fine, coarse, fine and coarse lead-silicate glass (CR).

![Figure 3](image3.png)

**Figure 3.** Expansion curves of foamed concrete mixes with: fine, coarse, fine and coarse boro-silicate glass (BS).
Figure 4. Expansion curves of foamed concrete mixes with: fine, coarse, fine and coarse green glass (GG).

Figure 5. Expansion curves of foamed concrete mixes with: fine, coarse, fine and coarse soda-lime glass (SL).

Figure 6. Expansion of foamed concrete mixes with and without crushed waste glass with different percentages after 60 days of ASR test.
7. Conclusion

From the experimental work the main conclusions can be as follows: It is possible to produce foamed concrete with using crushed waste glass as fine and coarse sand. The phenomenon of Alkali-Silica Reaction (ASR) occurs in foamed concrete mix without adding crushed waste glass as fine or coarse aggregate; however, it is less expansion than that of mixes contained crushed waste glass. For the same replacement percentage, the finer the glass particle sizes the lower the expansion value. Chemical composition of glass directly influences the expansion of foamed concrete mortar, where the maximum expansion values were observed in lead-silicate glass (CR) followed by soda-lime glass (SL) and borosilicate glass (BS), and finally green glass (GG).

Acknowledgments
The author is grateful all teaching and technician staff, Department of Civil Engineering Department at the University of Anbar for their support and guidance.

References

[1] M Malek, W. Lasica, M. Jackowski, and M. Kadiila, “Effects of waste glass additions as a replacement for fine aggregate on properties of mortar,” Material (Basel), vol. 13, no. 14, pp. 1–19, 2020, doi: 10.3390/ma13143189.

[2] P. J. Jagtap, M. R. Rathoed, S. Shahebaiz, and S. Murtaja, “A Review Paper on Comparative Study of Lightweight Concrete and Reinforced Concrete,” pp. 2616–2620, 2020.

[3] V. P. Sopoiev, O. I. Korkih, and M. Y. Izbarsh, “A study of the alkali-silica reaction in recycled glass concrete,” IOP Conf. Ser. Mater. Sci. Eng., vol. 907, no. 1, 2020, doi: 10.1088/1757-899X/907/1/1012062.

[4] A. Pirzad, “ENGINEERING Lightweight Concrete and its advantages compared with conventional concrete,” J. Civ. Eng. Res., pp. 5–12, 2017.

[5] J. Hamad Mohammed and A. G. Hamid, “Material, propertie and applications review of lightweight concretes,” Rev. Tech. la Faic. Ing. Unive. del Zuleia, vol. 37, no. 2, pp. 10–15, 2014.

[6] U. Ham, H. Amran, N. Firzadnia, and ALI. M. “Propertie and application of foamed concrete; A review,” Constr. Buildi. Mateir., volu. 1101, pp. 99–105, 2016, doi: 10.1016/j.conbuildmat.2015.10.112.

[7] “Use of Foamed Concrete in Construction,” Use Foam. Concr. Constr., no. July, 2005, doi: 10.1680/uofcic.34068.

[8] A. Tanveer, K. Jagdeesh, and F. Ahmed, “Foam Concrete,” vol. 8, no. 1, pp. 1–14, 2017.

[9] K. Ramimurthi, I. H. Kinhanandan Naimbair, and J. Indlu Sava Ranjiani, “classifications of the studie on propertie of foam concrete,” Cem. Concre. Composi., volu. 30, . 7 pp. 378–398, 2010, doi: 11.1026/j.cemconcomp.200804.007.

[10] S. J. Lam, , S. Ten, U. I. Lam, and U. I. Leu, “Hardened propertie of the lightweight of foamed concretes incorporation palm oil fuels as a filler,” Constr. Building. Material, volu. 47, pp. 38–77, 2014, doi: 10.1006/j.conbuildmat.2014.04.005.

[11] B. Atobybe Oolumoyewa, Odeyemyi Samsoon, A. Billo Sifiu, and U. Egbeifun Gephas, “Splitting tensile strength assessments of lightweight foamed concrete reinforced with waste tyres steel fibre,” Inter. G Jiv. Engin. Technolog., volu. 8, no. 8, pp. 1109–1107, 2017.
[12] A G. G. Naimbiar and G. Ramaimurthy, “Air void characterisations of foamed concrete,” Cem. Concrr. Reo., vol. 38, no. 3, pp. 222–231, 2008, doi: 11.1026/j.cemconreis.2007.10.019.

[13] Z. Liu, K. Zhao, C. Hu, and Y. Tang, “Effect of Water-Cement Ratio on Pore Structure and Strength of Foam Concrete,” Adv. Mater. Sci. Eng., vol. 2016, 2016, doi: 10.1155/2016/952094.

[14] N. S. Gones and I. McCarthry, “Views on potential of foam concrete in form of construction materials,” Maga. Concrete. Resorces, vol. 58, no. 2, pp. 22–32, 2006, doi: 10.1670/macro.2006.58.1.22.

[15] S. Chang, A. Elrahmaan, P. Sikoria, S Rucinska, I. Horszczairuk, and B. Stefan, “Estimation the effect of the expansion the waste glass aggregate on the property of lightweight concrete by the use of images-base approache,” (Basel), vol. 12, no. 13, pp. 1–17 2018, doi: 10.3390/ma10121354.

[16] A. Abd. Hillal, T. Thoim, and I. S. Dawso, “On entrained pore size distribution of foam concrete,” Constr. Buildi. Mater., vol. 75, pp. 227–233, 2015, doi: 10.1016/j.conbuildmat.2014.09.117.

[17] A. Fernandeis and H. A. S. M. Broikmans, “Alkali-Silika Reaction: An view. Part 1,” Metallogr. Microstructure. vol. 3, no. 5, pp. 267–266, 2013, doi: 10.107/t13633-023-085.

[18] L. Horn, “Target/emer therapy for meta-static non small cells lungs canecers,” JNCCN Journal of National Comprehensive CancersNetworks, vol. 14. pp. 677–679, 2015, doi: 10.6004/jncn.2015.0201.

[19] J. Liaudat, C. M. López, and I. Carol, “Diffusion-reaction model for ASR: Formulation and 1D numerical Implementation,” Comput. Model. Concr. Struct. - Proc. EURO-C 2014, vol. 2, no. Reardon, pp. 639–648, 2014.

[20] ASTM C150, “ASTM C150/C150M - 18 Standard Specifications for Portland Cement,” vol. i, pp. 1–9, 1999, doi: 10.1520/C0150.

[21] ASTM C33, “Concretes Aggregate I,” vol. i, no. S, pp. 1–10, 2011, doi: 10.1522/C033.

[22] ASTM C227, “Standard Test Method for Potential Alkali Reactivity of Cement-Aggregate Combinations ( Mortar-Bar Method ),” Annu. B. ASTM Stand., vol. i, pp. 1–5, 2003.

[23] ASTM C 128-01, “Standard Test Methods for Densites, The (Specific Gravity), and Absorption,” ASTM Int., pp. 1–6, 2001, [Online]. Available: www.astm.org, or.

[24] J. Stokes, I. Carol, and C. M. Lopez, “TESINA D’ESPECIALITAT Títol analysis of designed and assembyes of the AAR tri axial machines,” 2011. Available: https://upcommons.upc.edu/bitstream/handle/2099.1/14353/Jonathan Stokes - Tesina.pdf.

[25] Saccaini and M. S Bignonzy,“Alkali-Silica Reaction expansion behavior s of recely waste glass as fine aggregateused in concrete,” Cement. Concrete Rec., vol. 41, no. 4, pp. 530–537, 2011, doi: 11.1026/j.cemeconreses.2010.09.03.

[26] Dahn et. al., “Applications of micro X-ray diffractions to investigation of the reactions product formby the aASR in concrete con structures,” Cement. Concrete. Rec, vol. 78, no. Sept pp. 50–55, 2017, doi: 10.1017/j.cemeconreses.2017.07.12.

[27] D. Highway and T. Innovations, “Chapter 10 . Alkali-AGgregate Reactions,” 2006.

[28] Shayan and Xu, “Values-added utilisations of crushed waste glasses in concrete,” Cemem.
[29] C. Strength, “C Hemical R eactions of G Lass C Ullet,” *J. Mater.*, no. May 2011, pp. 412–417, 2001.

[30] K. Zheng, “Recycled glass concrete,” *Eco-Efficient Concr.*, no. August, pp. 241–270, 2013, doi: 10.1533/9780857098993.2.241.

[31] C. Shi, “Corrosion of Glasses and Expansion Mechanism of,” *October*, vol. 21, no. October, pp. 529–534, 2009.

[32] R. B. Figueira et al., “Alkali-silica reaction in concrete: Mechanisms, mitigation and test methods,” *Constr. Build. Mater.*, vol. 222, pp. 903–931, 2019, doi: 10.1016/j.conbuildmat.2019.07.230.

[33] P. Bažanet, G. Zih, and C. Meyir, “Fracture Mechanic of Alkali-Silica Reaction in concrete incorporation waste glass,” *J. Eng. Mech.*, vol. 126, no. 3, pp. 226–232, 2000.