Pergamon

Cement and Concrete Research 32 (2002) 223–226

CEMENT AND CONCRETE RESEARCH

Lightweight aggregate based on waste glass and its alkali–silica reactivity

V. Ducman*, A. Mladenovič, J.S. Šuput

Slovenian National Building and Civil Engineering Institute, Dimiceva 12, 1000 Ljubljana, Slovenia

Received 7 March 2001; accepted 17 August 2001

Abstract

The possible use of waste glass for the production of lightweight aggregate has been studied. The aggregate, in the form of highly porous granules, was produced by mixing together finely ground waste glass and an expansive agent and firing this mixture at a selected temperature. The expansive agent was chosen on the basis of the results of DTA/TGA experiments, which were carried out on some selected agents and confirmed by using a hot-stage microscope, where the temperature interval of the expansion was also determined. Pilot production of about 0.5 m^3 of the aggregate was performed in a rotary kiln, and the water absorption and bulk density of the aggregate so obtained were determined. Special emphasis was placed on the determination of the alkali–silica reactivity of the aggregate, and the results of initial tests for alkali–aggregate reaction were encouraging, given the high potential reactivity of the material. However, before such aggregate can be considered safe for general use in concrete, longer-term concrete prism tests need to be carried out, which would cover the range of mixes in which the aggregate is likely to be used. © 2002 Elsevier Science Ltd. All rights reserved.

Keywords: Waste glass; Expanded glass; Alkali–silica reaction; Lightweight aggregate

1. Introduction

Ideally, a lightweight aggregate should be round in shape, with a relatively impermeable outer surface, but it should also provide good adherence to the cement paste. Various different types of lightweight aggregate can be found on the market, of varying composition, density, surface texture, porosity, water absorption, and water absorption capacity. The most frequently used lightweight aggregates are based on expanded clay, shale, perlite, vermiculite, expanded polystyrene, and different kinds of pelleted or sintered waste, including sintered glass. Expanded glass aggregate appears to be quite promising in comparison with some other types of lightweight aggregate. It has a relatively high mechanical strength, low water absorptions, and high chemical and frost resistance. Either an open or a closed cell structure can be achieved depending on the firing regime and the added agents [1].

Expanded aggregates are produced by mixing finely ground glass with a suitable expanding agent and firing this mixture at a temperature above the softening point of glass so that a viscosity of less than $10^{6.6}$ Pa s is achieved. In the case of expansive agents consisting of one or more of the following compounds: Co_2O_3, $SrCO_3$, $CaSO_4$, MnO_2, talc, and water-glass, the agent degasses within the range between the softening point and the maximum firing temperature, and these gases remain trapped within the glass structure [1]. In the case of agents containing carbon, i.e. SiC, sugar, starch, or organic waste, the agent reacts with the glass or atmosphere, forming gases [1].

For all glassy aggregates, the possibility of alkali–silica reactivity needs to be taken into account. This is especially the case for aggregate based on waste glass, which may contain more than 70% silica. The combination of a high silica content and the amorphous structure of the glass means that as an aggregate, it is potentially deleterious and may react expansively with quite low levels of cement alkalies [2,3].

The objective of the investigations described in the paper was to ascertain as to what extent it is possible to produce lightweight aggregate from waste glass, and to

---

* Corresponding author. Tel.: +386-1-2804-438; fax: +386-1-2804-484.

E-mail address: vilma.ducman@zag.si (V. Ducman).

0008-8846/02/$ – see front matter © 2002 Elsevier Science Ltd. All rights reserved.
PII: S0008-8846(01)00663-9

determine the alkali–silica reactivity of the pilot scale aggregate thus produced.

2. Experimental

The range of decomposition of the selected expansive agent was determined by means of a DTA/TGA device, at a heating rate of 10°/min. The expansion process was followed by means of a hot-stage microscope, using the same heating rate up to a temperature of 1100 °C.

For the pilot production, waste glass derived from bottles and window glass was crushed and ground to a fineness of less than 100 μm. An expansive agent, which degasses at a temperature above the glass softening point, was chosen. The mixture was granulated by slowly adding a solution of methyl-cellulose to the glass-expansive agent mixture in a granulator. About 30–40 kg of the granules were fired in a rotary kiln at 880 °C between 10 and 15 min. This yielded about 0.5 m^3 of lightweight aggregate.

The apparent density, water absorption, and alkali–silica reactivity of the lightweight aggregate were determined. Apparent density was determined by weighing and determining the volume by the displacement of mercury. Water absorption was determined according to ÖNORM 3233 [4], by immersing the aggregate in water, as prescribed, for 30 min. Alkali–silica reactivity was determined by the ASTM chemical and the mortar bar tests. For the ASTM C 289 test [5], the fraction from 0.15 to 0.30 mm was used. For the ASTM C 227 test [6], the method was modified with regard to the aggregate particle size distribution and the aggregate-to-cement ratio due to the light weight of the aggregate. Mortar bars were prepared from 1 to 3 mm aggregate having a unit weight of 0.22 kg/m^3. The cement used contained 0.92% of Na_2O equivalent, the cement to aggregate ratio was 4.5:1, and the w/c factor was 0.388. The mortar bars were cured at a temperature of 38 °C and at a relative humidity greater than 95%. The texture of the mortar bars was observed by microscopic examination of thin sections.

3. Results and discussion

The most important factor in choosing a suitable expansive agent is the temperature range of its decomposition, which should be above the glass softening point but still within the range where the viscosity of the glass is high enough to trap the gas inside the glass. The suitability of the investigated expansive agent was determined by DTA/TGA analysis and confirmed by using a hot-stage microscope. This method has been fully described in previous papers [7,8]. It is briefly summarised here in Figs. 1 and 2. From Fig. 1, it can be seen that the first decomposition of the selected expansion agent occurred at a temperature above 600 °C, with a maximum occurring at 658 °C, followed by an 8.8% loss in mass, confirming that the reaction gases had been released. The second decomposition occurred at a temperature above 700 °C, with a maximum at 757 °C. This decomposition was also accom-

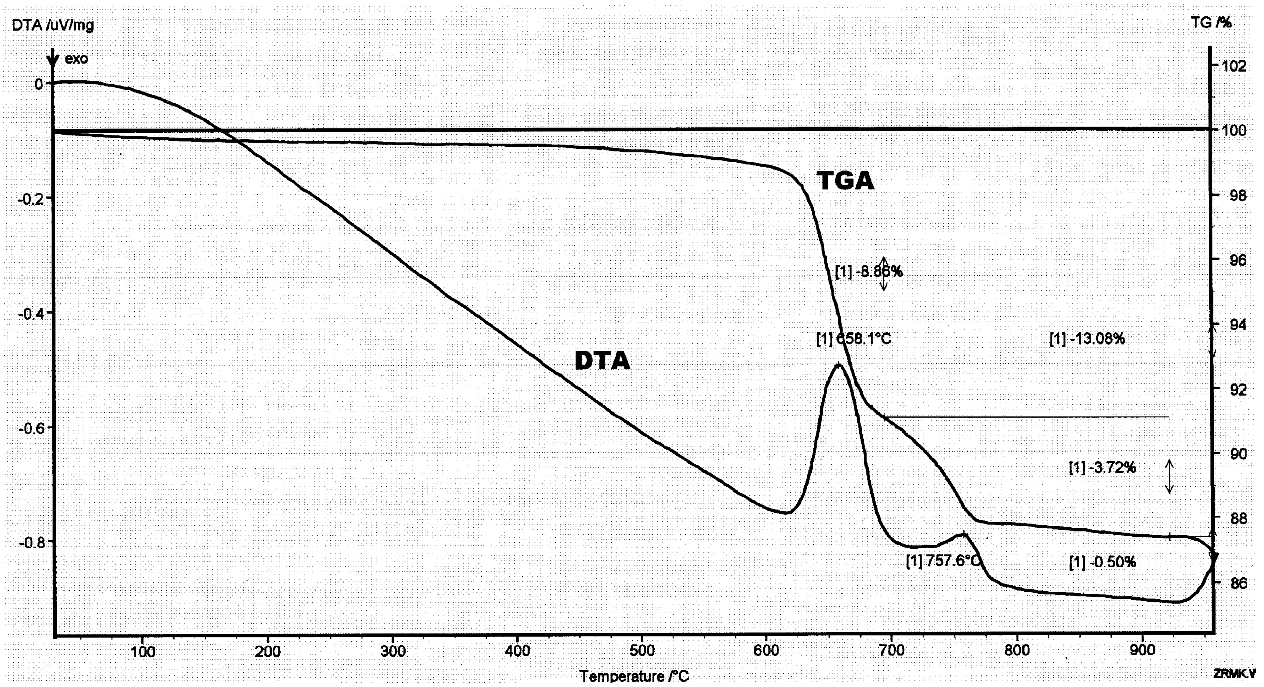

Fig. 1. DTA/TGA analysis of the expansive agent.

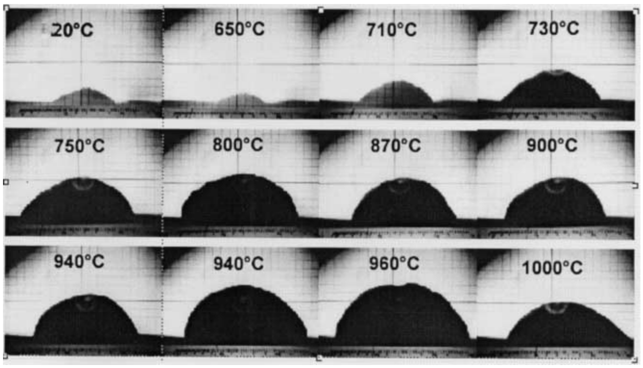

Fig. 2. Hot-stage microscope images of the aggregate during firing.

panied by gas release, with a 3.7% loss in mass. The expansion process was followed "in situ" by using a hot-stage microscope, and this is presented in Fig. 2. It can be seen from this figure that the gas from the decomposition at 700 °C was not trapped inside the glassy structure, because it is too porous. The second decomposition, at 737 °C (see Fig. 1), showed good correlation with the expansion on the hot-stage microscope within the range between 750 and 800 °C. The DTA/TGA peak at 930 °C also correlated with images on the hot-stage microscope, where further growth of the aggregate was observed. It has been shown [7] that if the aggregates are fired at a lower temperature a finely porous structure occurs, whereas firing above 900 °C results in a coarse porous structure.

The firing temperature used in the rotary kiln was approximately 880 °C. About 0.5 m^3 of the aggregate was produced, with an average apparent density of 0.18 kg/m^3 ranging down to 0.15 kg/m^3. The unit weight for the fraction below 4 mm was 0.22 kg/m^3, and water absorption was 11.0% by mass. A typical cross section of the aggregate is shown in Fig. 3. It can be seen that the aggregate is highly porous, with individual pores having diameters from 0.1 to 1 mm.

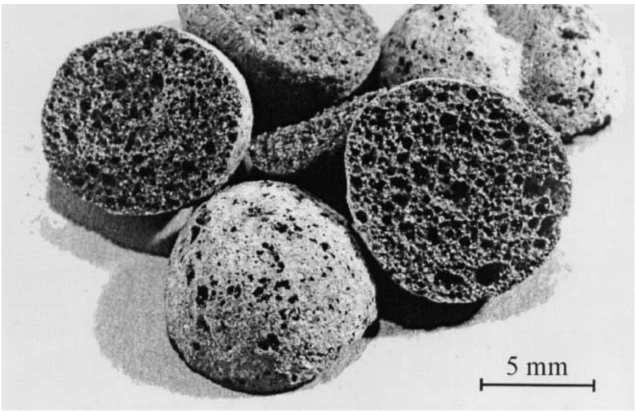

Fig. 3. Cross section of granules from the pilot production.

Table 1
Average linear strain of the tested mortar bar specimens, depending upon the time of exposure

Time of exposure (days)	Linear strain (%)
14	−0.043
28	−0.054
56	−0.065
90	−0.079
120	−0.082
163	−0.036
190	−0.047
228	−0.047

The results of the alkali–silica reactivity tests were, according to ASTM C 289, as follows: Sc = 2366.6 mmol/l and Rc = − 708.0 mmol/l. Usually Rc has a value above zero, which represents a decrease in alkalinity. In the case of the aggregates described in this paper, Rc had a value that was significantly below zero. The alkalinity of the solution to which the sample was exposed was 887 mmol/l. After treatment, the alkalinity of the solution was 1595 mmol/l, which suggests that the alkalinity increased due to the release of alkalies from the expanded glass aggregate.

Length measurements on the mortar bars were carried out up to 228 days (Table 1 and Fig. 4). According to the requirements of ASTM C 227, the aggregate passes the test if the expansion of the mortar bars does not exceed a value of 0.1% after 6 months of exposure. As can be seen in Table 1, after 228 days of exposure, the prisms actually shrank.

After 228 days of exposure no cracks, gel spots or wet patches were observed on the surfaces of the mortar bars. The mortar bars were then thin sectioned, and examined under an optical polarising microscope. Fig. 5 shows the typical microscopic texture of an exposed bar. The texture shows the porous structure of the aggregate and also conchoidally cracked gel inside a pore, as indicated by an arrow. The gel was clearly identified by its amorphous structure. The results of the above described tests for alkali–aggregate reaction were encouraging even for aggregates based on waste glass, which is highly reactive according to ASTM C 289. Further long-term concrete

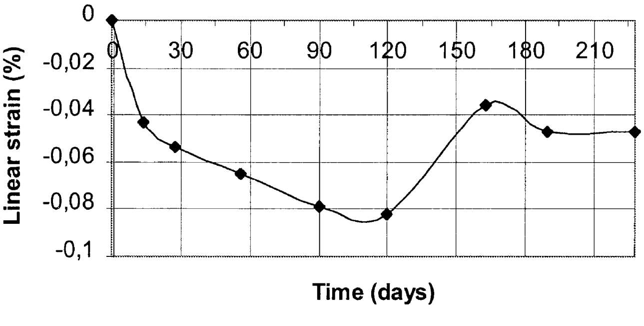

Fig. 4. Average linear strain of the mortar bar specimens depending upon the number of days of exposure.

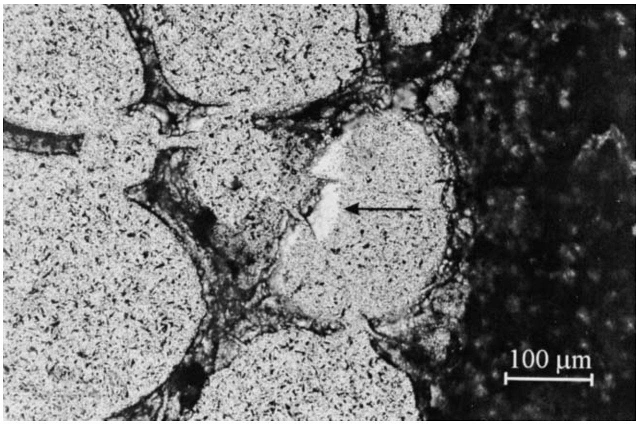

Fig. 5. Microscopic texture of a mortar bar after testing by ASTM C 229 for 228 days (plain light, thickness of sample approximately 40 μm).

prism tests of mixes in which this aggregate is likely to be used need to be performed in order to exclude the possibility of damage [9].

4. Conclusions

Lightweight aggregate based on powdered waste glass was prepared by granulating the glass with an expansive agent and heating this mixture in a rotary kiln to 880 °C. The temperature range of expansion was determined to be above 750 °C by means of DTA/TGA and a hot-stage microscope. Apparent density and water absorption, determined in pilot production, were 0.18 g/m^3 and 11 mass%, respectively.

The results of tests of the alkali–silica reactivity of the expanded aggregate according to ASTM C 289, the chemical method, showed that the aggregate is highly reactive and indicated that the aggregate is an additional source of alkalies. However, the results of the mortar bar test according to ASTM C 227 using Portland cement containing 0.92% Na_2O equivalent showed that, although the expanded glass aggregate is highly reactive, it did not cause either expansion or cracks in the mortar bars. This is attributed to the porous structure of the aggregate, which is able to accommodate the large amount of gel produced. The aggregate appears to behave like a rhyolitic pumice [2].

References

[1] S. Köse, G. Bayer, Schaumbildung im System Altglas-SiC und die Eigenschaften derartiger Schaumgläser, Glastech. Ber. 55 (7) (1982) 151–160.

[2] D.A. St John, A.B. Poole, J. Sims, Concrete Petrography, Arnold and Wiley, New York, 1998, Chapter 6.7.

[3] L. Dolar-Mantuani, Handbook of Concrete Aggregates, Noyes Publications, New Jersey, 1983, pp. 80–113.

[4] ÖNORM 3233/1971, Blähton.

[5] ASTM C 289/94, Test Method for Potential Alkali Reactivity of Aggregates (Chemical Method).

[6] ASTM C 227/90, Standard Test Method for Potential Alkali Reactivity of Cement–Aggregate Combinations (Mortar-Bar Method).

[7] V. Ducman, M. Kovačević, High porosity granules produced from waste glass, Kovine, Zlitine, Tehnol. 33 (5) (1999) 377–379.

[8] V. Ducman, M. Kovačević, Proizvod na osnovi penjenega stekla, postopek za njegovo proizvodnjo in uporaba (Product based on foamed glass, method for production, and use), SI patent 9700161, 1999.

[9] P.C. Hewlett, Lea's Chemistry of Cement and Concrete, Arnold and Wiley, New York, 1998.