Influence of zeolite additive on properties of autoclaved aerated concrete

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Received 26 January 2006; received in revised form 4 July 2006; accepted 22 August 2006

Abstract

In this experimental study, the effect of zeolite on the properties of autoclaved aerated concrete (AAC) was investigated. Zeolite was used as a quartzite replacement in conventional AAC mixtures. The zeolite containing AAC (ZAAC) specimens were prepared at bulk densities of 270–500 kg/m³. The specimens were examined by X-ray diffraction, X-ray fluorescence, and thermal analysis. Bulk density, compressive strength and thermal conductivity parameters were investigated. According to the results of research, the commercial AAC is mainly composed of tobermorite, quartz and anhydrite, but the specimens of ZAAC, besides tobermorite and quartz, contain unreacted anhydrite and clinoptilolite phases. XRD patterns of ZAAC obtained after treatment at 700–1000 °C show that wollastonite, gehlenite and orthoclase are the new phases formed. It was observed that application of zeolite in AAC significantly lowered the thermal conductivity of autoclaved products (0.08–0.12 kcal/m h °C) providing the compressive strength at the level of 1.22–3.34 N/mm².

Keywords: Autoclaved aerated concrete; Thermal treatment; Zeolite; X-ray diffraction; Compressive strength; Thermal conductivity

1. Introduction

Autoclaved aerated concrete (AAC) is produced using cement, lime, siliceous materials (quartz sand, fly ash) and small quantities of aluminum powder [1]. These components are mixed with water, molded and transferred to a porous mass by generation of a hydrogen gas at atmospheric pressure. The aluminum powder acts as a gas-forming agent. Following the reaction time of several hours, soft and workable mass is obtained due to the hydration of unslaked lime and cement. Then, the shaped material is cured for nearly 10 h at 180–190 °C using saturated steam at a pressure of around 12 bar. The final products have an average compressive strength of 2.5–7.5 MPa and a oven-dry unit weight of 400–600 kg/m³ depending on the quality class (G2–G6 according to TS 453).

With steam curing, an initially formed C–S–H phase is transferred to tobermorite (5CaO 6SiO₂· 5H₂O) by reaction with dissolved silica with excess quartz remaining unreacted. It has been reported that the hydrothermal reactions in the CaO–SiO₂ system are controlled by the dissolution of quartz [2–5], which is the dominating factor for the processing time. Isu et al. [6] studied the effect of quartz particle size and found that the crystallinity of tobermorite was increased with increase of quartz particle size. Gyrolite (Ca₄(Si₆O₁₅)(OH)₂· 3H₂O) was formed with an increased autoclaving time in case when finer quartz was used. Isu et al. [7] showed that the formation of gyrolite after reaction time of 64 h using finer quartz decreased the compressive strength and the Young’s modulus due to changes in the micro-pore size distribution.

Hauser et al. [8] used fly ash from cellulose industries in AAC mixtures and observed that, at a high proportion of fly ash, the formation of calcium silicate hydrate phases was delayed with corresponding drop in strength and increase in shrinkage. Wagner et al. [9] found that the anisotropy in AAC could be precisely monitored by...
measurement of gas permeability rather than determining
the compressive strength values, especially for lower-
density products. Other researchers have studied the
compressive strength and drying shrinkage of AAC
[10–12].

The aim of this work was to investigate the effect of
zeolite as siliceous material replacing quartz sand in AAC.
For this purpose, the effect of Manisa-Gördes clinoptilolite
(Turkey) on chemical and mechanical properties of ZAAC
was examined.

2. Experimental study

2.1. Materials

Zeolite used in this study was obtained from Gördes
Zeolite Works (Turkey). The specific gravity of the sample
was determined as 2.28 and the chemical composition of
the sample is given in Table 1. The chemical composition of
conventional siliceous material used in AAC composition
is given Table 1 [13]. The XRD analysis of zeolite sample
shows that the main mineral is clinoptilolite and cristobalite
is present in minor quantities.

XRD patterns of the sample treated at temperatures
between 100 and 800 °C (Fig. 1) show that the peak
intensities of clinoptilolite are decreased due to lattice
contraction and thermal collapse of the framework at
800 °C. The TG/DTA data given in Fig. 2 is in agreement
with XRD results showing continuous dehydration up to
700 °C with the release of water and an exothermic event at
924.2 °C due to collapse of the structure. At temperatures
between 900 °C and 1300 °C color changes are observed
and new phases are formed (Fig. 3). Yellowish pale brown
color at 1150 °C (opal-CT, quartz and feldspars) turns into
gray at 1300 °C with the observed phase of quartz.

2.2. Sample preparation

Based on the proportions of the raw mixtures [5,6,11]
ZAAC samples were prepared at varying bulk densities
with mean ratio of Ca/(Al+Si) = 0.48. In all these samples
zeolite with size of less than 90 μm was used to replace
quartz at a dosage of 100%. The samples were cast using
300 x 200 x 200 mm steel molds, initially hardened at
atmospheric pressure and temperature of around 50 °C
for 4h and then autoclaved at 200 °C under saturated
steam pressure of 11.5 bar for 12 h using the facilities of
Çimentaş AAC factory.

2.3. Methods of investigation

Compressive strength and bulk density were determined
in accordance with TS 453 “Gas and foam concrete

<table>
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<tr>
<th>Oxide</th>
<th>SiO₂</th>
<th>Al₂O₃</th>
<th>K₂O</th>
<th>CaO</th>
<th>Fe₂O₃</th>
<th>MgO</th>
<th>Na₂O</th>
<th>TiO₂</th>
<th>L.O.I.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zeolite</td>
<td>70.74</td>
<td>12.77</td>
<td>3.59</td>
<td>2.21</td>
<td>1.30</td>
<td>1.16</td>
<td>0.53</td>
<td>0.023</td>
<td>7.55</td>
</tr>
<tr>
<td>Quartzite</td>
<td>97.58</td>
<td>0.31</td>
<td>0.03</td>
<td>0.14</td>
<td>1.20</td>
<td>0.10</td>
<td>0.10</td>
<td>—</td>
<td>0.03</td>
</tr>
</tbody>
</table>

Fig. 1. XRD patterns of zeolite between 100 and 800 °C.

Fig. 2. TG/DTA curves of zeolite.
material and elements for buildings” [14]. Compressive strength tests were performed on 100 mm cubic specimens at the age of 28 days. The loading rate was arranged to achieve the failure in 30 s by keeping the stress rate between 0.05 and 0.25 N/mm². Bulk density was determined on 150 × 100 × 40 mm samples dried at 105 ± 5 °C. Thermal conductivity measurements were done in accordance with TS ISO 8302 “Thermal insulation: determination of steady-state thermal resistance and related properties; guarded hot plate apparatus” [15] using Kemtherm QTM-D3 thermal conductivity meter on dry samples.

Chemical composition of zeolite was determined by X-ray fluorescence analysis using Rigaku RIX 3000 spectrometer. X-ray diffraction (XRD) analyze was carried out on a Rigaku Geiger Flex X-ray diffractometer and the TG/DTA tests were performed using Rigaku TAS 100 Thermoflex TG 8110 thermal analyzer.

3. Results and discussion

3.1. Bulk density, compressive strength and thermal conductivity

Zeolite-based AAC (ZAAC) samples were prepared at the oven-dry unit weight of 270–500 kg/m³ by controlling the quantity of Al used as foaming agent. Change of ZAAC bulk density at different Al/∑Al ratio is given in Fig. 4, showing that the bulk density increases sharply with decrease of Al powder dosage.

Changes in compressive strength and thermal conductivity values vs. dry bulk density of ZAAC and commercial AAC are given in Figs. 5 and 6 (as per as TS 453 and TS 415 EN 12939 [14,16]). The compressive strength and the thermal conductivity values are reduced with decrease of bulk density of these materials. Similar thermal conductivity values were observed for ZAAC and AAC products of the same density.

3.2. X-ray diffraction and thermal analysis of products

XRD analyses (Fig. 7) show the presence of tobermorite, quartz and anhydrite in commercial AAC and formation of wollastonite as a new phase at 850 °C. Typical TG/DTA curve of commercial G-2 grade AAC is given in Fig. 8. Two
endotherms observed for AAC at 225.4°C and at 565.0°C are due to loss of molecular water and conversion of $\alpha$-SiO$_2$ to $\beta$-SiO$_2$, respectively. The sharp exotherm at 831.5°C is associated with crystallization of wollastonite.

The ZAAC contain unreacted anhydrite and clinoptilolite phases besides tobermorite and quartz (Fig. 9). XRD patterns obtained after treatment of the product between 700 and 1000°C show that wollastonite, gehlenite and orthoclase are newly formed phases. Clinoptilolite (zeolite) peaks were also observed at 700–800°C in sample. While gehlenite was observed at temperature 800–1000°C, wollastonite and orthoclase were observed only at 900–1000°C. On the other hand, there was no detected change with anhydrite phase. Initially formed tobermorite disappeared with increase in temperature.

DTA curve for ZAAC (Fig. 10) shows that an endotherm occurring at 161.7°C is due to loss of molecular water; two exotherms at 755.0 and 798.5°C are due to lattice contraction and thermal collapse of the framework of excess clinoptilolite and a broad exotherm at 877.1°C can be attributed to formation of wollastonite as a new phase.

4. Conclusions

The following conclusions can be made based on the results of this investigation:

1. Zeolite can be used as a component of AAC partially replacing quartzite and providing the strength similar to
conventional AAC. With increase in the bulk density of ZAAC and AAC the compressive strength of these materials increases proportionally.

2. Use of zeolite to replace quartzite in production of AAC provides the thermal conductivity values similar to conventional AAC at the same bulk density.

3. Commercial AAC is mainly composed of tobermorite, quartz and anhydrite, but ZAAC contains unreacted anhydrite and clinoptilolite phases besides tobermorite and quartz.

4. XRD patterns obtained after treatment of ZAAC between 700 and 1000 °C shows that wollastonite, gehlenite and orthoclase are the new phases formed at these temperatures.

References