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INFLUENCE OF QUARTZ PARTICLE SIZE ON THE CHEMICAL AND MECHANICAL PROPERTIES OF AUTOCLAVED AERATED CONCRETE (II) FRACTURE TOUGHNESS, STRENGTH AND MICROPORE

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ABSTRACT

The development of mechanical properties of autoclaved aerated concrete (AAC) block was investigated using ground quartz of different particle sizes. The samples were prepared at 180℃ under saturated steam pressure for various times from 0.5 to 64 h. With increasing tobermorite formation, the compressive strength, Young's modulus and fracture energy increased for the samples made using the coarser quartz, and decreased for the samples made using the finer quartz. After the completion of tobermorite formation, the coarser quartz yielded the higher compressive strength, Young's modulus, fracture energy and crack growth resistance. Using the finer quartz, gyrolite was formed by the decomposition of tobermorite after 64 h autoclaving, reducing the compressive strength and Young's modulus with changes in the micropore size distribution.

Introduction

Autoclaved Aerated Concrete (AAC) is a lightweight construction material with a bulk density of 500 kg/m^3 and a volume porosity of 80 %. AAC is mainly composed of 1.1-nm tobermorite ($5CaO{\cdot}6SiO_2{\cdot}5H_2O$) and quartz. Tobermorite is the main binder of

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AAC formed hydrothermally from calcareous materials (cement and lime) and siliceous materials (quartz sand), while quartz is the residue of the siliceous starting material. Our previous report discussed the influence of the particle size of quartz in starting materials on the formation of tobermorite [1]. In this paper, using the same block samples, the development of mechanical properties during the autoclaving process will be discussed.

Many works have been reported on compressive strength as a representative mechanical property of autoclaved calcium silicate materials in relation to the other properties: crystallinity and amounts of the tobermorite [2-8], specific surface area [5], porosity and pore size distribution [5,9-12] and crystal morphology [3,10-12]. Regarding the development of the mechanical properties of AAC during the autoclave processing, the compressive strength increases with increase in the amount of tobermorite formation until the completion of the reaction [6,7]. However, the compressive strength itself does not always indicate the resistance to the damage from the complex stresses which may be produced during transportation and building construction. Therefore, RILEM recommends the measurement of the fracture toughness using fracture energy (G_F) as one of the physical parameters for evaluating AAC [13,14]. AAC giving higher compressive strength does not always show higher toughness [8,15]. A few works have been reported on the fracture toughness of AAC. The G_F increases with an increase in bulk density [8,15]. Larger particle size of the residual quartz gave the higher fracture toughness [16]. However, the development of fracture toughness and fracture behavior during the autoclaving process have not yet been reported.

The objective of the present work was to investigate the influence of the particle size of quartz used as the starting material to the development of mechanical properties of AAC on the autoclaving process.

Experimental Procedure

Samples

All the samples used were the same blocks described in the previous paper [1]. The samples A, B, C and D were made using ground quartz sand having different mean particle diameters of 4.3 μm, 7.5 μm, 12.4 μm and 32.3 μm, respectively.

Examination of Products

Micropore distribution was measured by the mercury intrusion method (Autoscan-33, Quantachrome) for the sieve fraction 600-2000 μm. Although the mercury intrusion pore indicates pore entry diameter, it will hereafter be referred to as the micropore diameter.

The compressive strength and the Young's modulus were measured using two cut specimens (100mm cube) having 10 ± 2 wt% water contents from each block sample. The loading was parallel to the direction of expansion through foaming during the hardening of the green body, since the compressive strength is influenced to the foaming direction.

A compact tension (CT) test was employed for the fracture toughness measurements. The 100 mm cubes were dried to 10 ± 2 wt% water content at room temperature, then notched to a depth of 50 mm in a fixed direction selected in regard to practical use. The notch tip was finished with a radius of curvature of 0.15 mm. The loading rate was 0.05

mm/min. The crack mouth opening displacement was measured by a clip gauge. Fracture energy G_F was calculated by the RILEM recommended method [13]. To evaluate the crack growth resistance by resistance curve (R-curve), the unload-compliance method was carried out. For the R-curve, the crack length (Δa) was calculated from the inclinations on the load-displacement curve and evaluated against the J integral [17].

Results and Discussion

Regarding the reaction products [1], the samples A, B and C gave tobermorite after 0.5 h autoclaving, while it took 2 h to form tobermorite for the coarsest quartz (sample D). The coarser quartz gave the larger crystallite size of tobermorite, and yielded the higher degree of reaction of the quartz after longer periods of autoclaving, indicating higher amounts of tobermorite formed. In addition, the finer quartz (A and B) gave gyrolite by the decomposition of tobermorite after 64 h.

Pore Distribution

Figure 1 shows the micropore distributions of the samples autoclaved for various times. Mitsuda et al. reported that the modal micropore diameter was 6 μm for the green body, which shifted to 0.05-0.1 μm with the tobermorite formation without a change in total pore volume [6,7]. A similar phenomenon was clearly observed for the sample made using the coarsest quartz. After 0.5 h, sample D having C-S-H as a reaction product gave a broad peak around 0.1-1 μm, which tended to be sharper and shifted to 0.02 μm after 8 h. On the other hand, these phenomena were not observed for the samples using the finer quartz due to the tobermorite formation after 0.5 h. After the formation of tobermorite as a main binder, all the blocks showed modal micropore diameters decreasing with increase in the particle size of the quartz: 0.05 μm (A), 0.04 μm (B), 0.03 μm (C) and 0.02 μm (D).

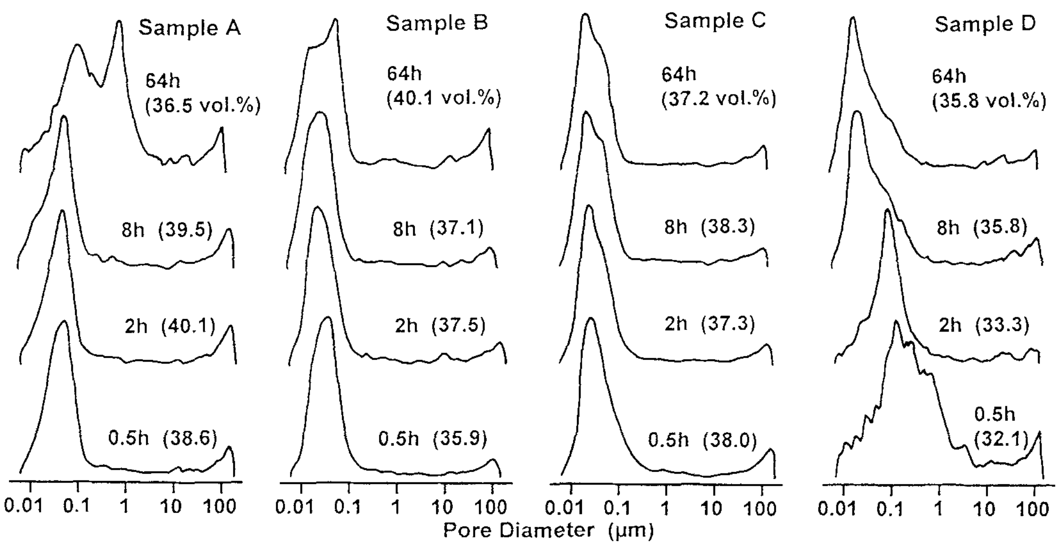

FIG. 1
Pore size distributions of the samples autoclaved for various times, showing micropore volume % in parentheses.

These results agree well with the amounts of tobermorite and its crystallite size [1]. Total pore volume seemed to be unaffected by autoclaving time. This agrees well with the results reported by Mitsuda et al. [6,7].After 64 h, the maxima of the pore size in the samples A and B were shifted to larger sizes. In particular, the peak separated into 0.1 and 1 μm for the sample A, resulting from the gyrolite formation.

Compressive Strength and Young's Modulus

Figures 2 (a), (b) and (c) show the bulk density, the compressive strength and the Young's modulus as a function of autoclaving time, respectively. The compressive strength of AAC increased with the tobermorite formation, and then slightly decreased after the end of the reaction, as previously reported [6,7]. This phenomenon was observed when the coarser quartz was used (C and D). For samples A and B made using the finer quartz, the compressive strength decreased with the autoclaving time up to 32 h, and then decreased largely after 64 h. The remarkable decreases in the compressive strength were caused by the gyrolite formation, with the change in the pore size distribution. The compressive strength after longer autoclaving tends to increase with the increase of the particle size of quartz, and thus with the increase of the amounts of tobermorite and of its crystallinity, showing good agreement with the previous reports [4]. The Young's modulus showed similar results to the compressive strength.

Fracture Energy G_F

Figure 2 (d) shows the fracture energy G_F as a function of autoclaving time. The changes of the G_F with the autoclaving time were smaller than those of the compressive strength. For samples C and D made using the coarser quartz, G_F increased with autoclaving time. On the other hand, for samples A and B made using the finer quartz, G_F decreased with autoclaving time. In contrast to the compressive strength, the G_F did not decrease on the formation of gyrolite in samples A and B after 64 h. Comparing the G_F after 4 h, the coarser quartz yielded the higher G_F.

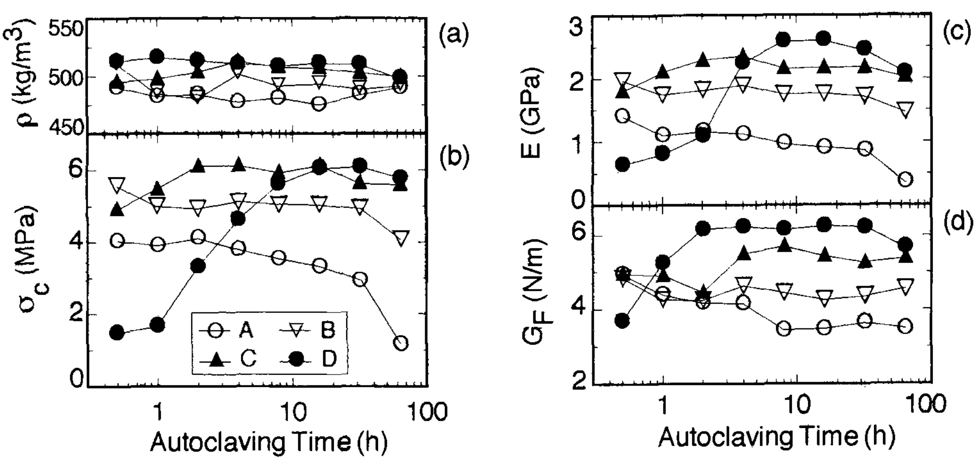

FIG. 2

Mechanical properties of the samples as a function of autoclaving time; (a) bulk density; (b) compressive strength; (c) Young's modulus; (d) fracture energy.

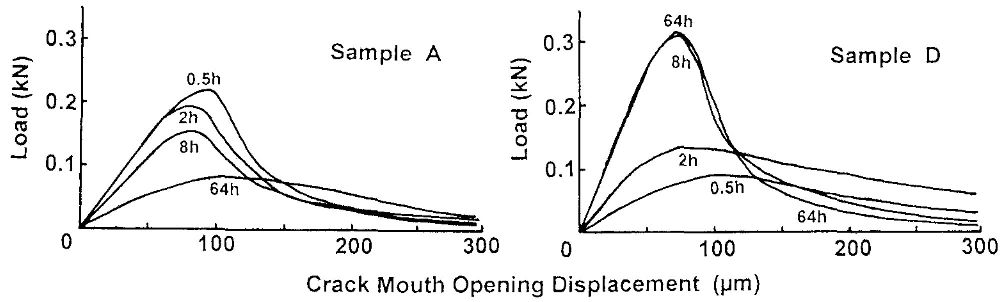

FIG. 3
Load- displacement curves of the samples autoclaved for various times.

Crack Growth Resistance

Figures 3 and 4 show the load-displacement curves by CT test and R-curves, respectively, indicating the fracture behavior during the deformation process. The deformation energy for the linear (elastic) behavior indicated the linear zone at the early stage of loading in Fig. 3 and the J integral at $\Delta a=0$ in Fig. 4. Using the coarsest quartz (D), the value increased with the autoclaving time, while it decreased for the finest quartz (A). This agrees with the G_F results. For the crack growth resistance, which indicated the inclination in the R-curve, the coarser quartz gave the higher resistance. The formation of gyrolite in the samples A and B after 64 h gave the decrease of the fracture energy.

Influence of Particle Size of Quartz on the Mechanical Properties

The particle size of quartz used as the starting material influenced the mechanical properties of AAC as mentioned above: the coarser the quartz, the higher were the compressive strength, Young's modulus and fracture toughness. Teramura et al. reported that the coarser particles of residual quartz contribute to the higher toughness [16]. In addition to the particle size of quartz residue, other factors, such as microtexture and the amounts of tobermorite formed, need to be taken into consideration. Taylor suggested that the morphology of calcium silicate crystal affects the compressive and flexural

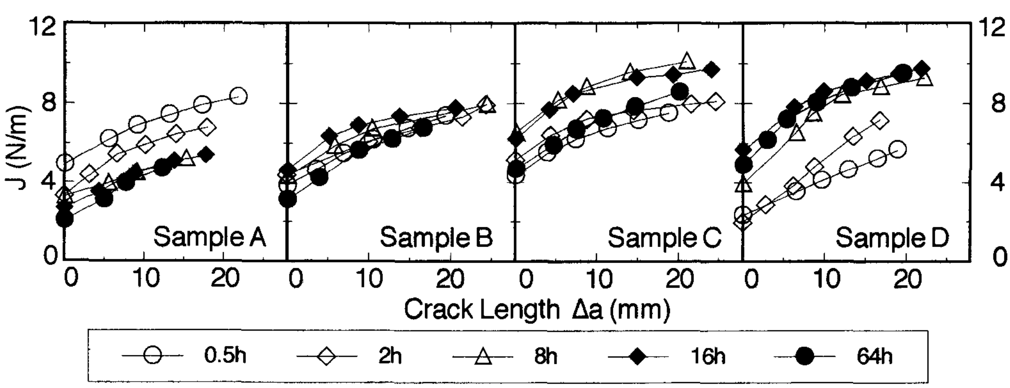

FIG. 4
R-curves of the samples autoclaved for various times.

strength, the needle-shaped crystals giving the higher flexural strength [3]. In the present work, the coarser quartz as the starting material gave the higher amounts of tobermorite formed and larger crystallite size. Those samples with the large particle size of residual quartz were thought to cause the higher compressive strength and fracture toughness.

Conclusions

(1) The maximum pore size formed by the tobermorite formation became smaller by using the coarser quartz.
(2) The compressive strength and Young's modulus increased with the tobermorite formation for the samples using the coarser quartz. The coarser quartz gave the higher compressive strength and Young's modulus.
(3) Fracture energy and the crack growth resistance increased by using the coarser quartz.
(4) Gyrolite was formed after 64 h in the block using the finer quartz, resulting in the decrease in the compressive strength and the Young's modulus with the changes in the micropore distribution.

Acknowledgments

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