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Applicability of Stone Powder Sludge as a Substitute Material for Quartz Sand in Autoclaved Aerated Concrete

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Abstract

Stone powder sludge is a byproduct of the crushed aggregate industry, and most of it is dumped with soil in landfills. The disposal of stone powder sludge presents a major environmental problem. This paper investigates the effects of stone powder sludge on the fluidity, density, strength and micro-structure properties of AAC(autoclaved aerated concrete) samples. Stone powder sludge was obtained from a crushed aggregate factory in order to investigate its applicability as a substitute for quartz sand in AAC. To determine the properties of the AAC samples produced with stone powder sludge, specimens containing different foam ratios were produced. Flow value, density, compressive strength, tensile strength and flexural strength of the samples were tested, and X-ray diffraction (XRD) was performed. The test results indicated that the compressive strength of AAC specimens (F120) with stone powder sludge was higher than that of AAC specimens (Q120) with quartz sand for same foam ratio of 120%. For all XRD diagrams, a higher number of tobermorite peaks was shown for the F120 sample than for the Q120 sample, which may explain the slightly higher strength gain in the F120 sample.

Keywords : autoclaved aerated concrete, stone powder sludge, density, compressive strength

1. Introduction

Stone powder sludge is a byproduct of the crushed aggregate industry. It is collected using a filter press from the washed sludge water obtained after the cleaning of crushed sand with water while manufacturing crushed aggregates. In Korea, crushed aggregate factories produce approximately 7.5 million tons of stone powder sludge annually[1]. Most of this is dumped with soil in landfills, and its disposal is a major environmental problem. As such, there is need to find a solution for its safe disposal.

Stone powder sludge usually consists of SiO_2 and Al_2O_3 in amounts similar to those in Class F fly ash[1], which is used as a siliceous material for manufacturing autoclaved aerated concrete(AAC). Generally, AAC is produced using cement, lime, siliceous materials (quartz sand, fly ash etc.), and small quantities of aluminum powder[2,3]. These components are mixed with large volumes of water and are then molded to produce a cellular body at atmospheric pressure, followed by autoclaving at 200℃ under a saturated steam pressure for several hours. With steam curing, an initially formed C–S–H phase is transformed to tobermorite ($5CaO \cdot 6SiO_2 \cdot 5H_2O$) by reaction with dissolved silica, while the excess quartz remained unreacted. It has been reported that the hydrothermal reactions in a

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$CaO-SiO_2$ system are controlled by the dissolution of quartz[4,5,6]. The influence of alternative SiO_2 sources, as well as various Al compounds, on phase formation under hydrothermal conditions has been studied by many researchers[7,8]. Kurama et al.[7] examined the use of coal bottom ash as an aggregate to produce aerated concrete. Their findings indicated that the use of the coal bottom ash caused a decrease in the unit weight of the AAC produced using different bottom ash replacement ratios. Mostafa[8] investigated the influence of air-cooled slag on the physicochemical properties of AAC samples. He replaced the lime and sand present in AAC with air-cooled slag. Based on his findings, he concluded that replacing sand and lime with slag enhances the compressive strength of an AAC sample by up to 50%, especially at short curing times (2 and 6h).

In addition, during the past several years, some researchers have investigated the use of stone powder sludge in the cement and concrete industries[1,9]. Takayuki and Masaru[9] evaluated the applicability of crushed stone powder and recycled concrete powder to high fluidity concretes in order to prevent concrete segregation. They found that the use of these powders resulted in an increase in the plastic viscosity (which is related to the segregation resistance) of mortar. This increase was directly proportional to the quantity of the powders used. Choi et al.[1] investigated the effects of stone powder sludge on the microstructure and strength of alkali-activated fly ash and blast furnace slag mixes. Their findings showed that the compressive strength of the alkali-activated blast furnace slag mixes that used stone powder sludge was higher than that of the alkali-activated blast furnace slag control mix.

This study examines how the fluidity of fresh sample, density, compressive, tensile, flexural strength, and XRD patterns of hardened AAC sample using stone powder sludge were affected depending on the various added water content and foam ratios in order to investigate the applicability of stone powder sludge as a substitute for quartz sand in AAC.

2. Materials and methods

2.1 Materials

ASTM Type I Portland cement and quartz sand with SiO_2 (90.1%) were used. Granite stone sludge consisting primarily of SiO_2 and Al_2O_3 served as stone powder sludge. The water content of the stone powder sludge was 28% by weight. The specific gravities of the Portland cement and stone powder sludge were 3.15 and 1.95, respectively. The compositions are listed in Table 1. Figures 1 and 2 show the grading curve and XRD pattern of the stone powder sludge, respectively. The sludge particles had a mean diameter of about 7μm. Slaked lime (CaO 68.3%), anhydrous gypsum (CaO 38.3% and SO_3 54.4%), and alumina cement with a specific gravity of 2.95 and a Blaine fineness of 5,210cm^2/g (BK and NH Chemical Co., Korea) were selected to promote the hydrothermal reaction after a careful survey of the literature[2,4,6].

Table 1. Chemical composition of used materials

Material*	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	SO_3	LOI
C	21.4	6.3	2.9	61.4	2.7	0.13	0.9	2.2	
SPS	63.2	16.2	3.5	2.9	1.64	2.11	5.23	–	
AC	4.2	54.7	0.6	36.9	–	0.08	0.23	0.2	
SL	–	–	–	68.3	–	–	–	–	26.7
AG	3.7	0.7	–	38.3	–	0.01	0.03	54.4	2.9
QS	90.1	5.7	1.0	–	0.1	0.14	1.72	–	

*C(Cement), SPS(Stone powder sludge), AC(Alumina cement), SL(Slaked lime), AG(Anhydrous gypsum), QS(Quartz sand)

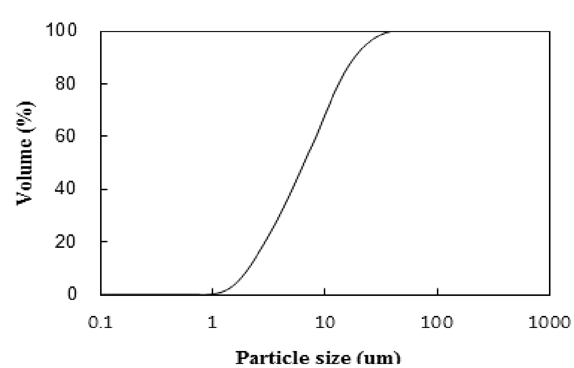

Figure 1. Grading curve of stone powder sludge

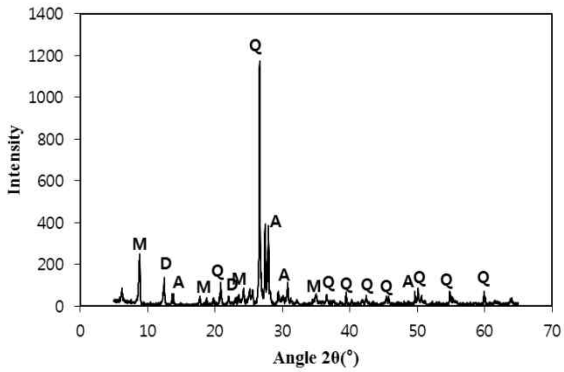

Figure 2. XRD patterns of stone powder sludge. Q; quartz, M; muscovite, A; albite, D: dickite

2.2 Mix proportions and specimen preparation

Generally, additional water should be added to the stone powder sludge for mixing with other materials due to the low fluidity and high viscosity of the stone powder sludge itself. To investigate the fluidity variation of the stone powder sludge, added water content at addition ratios of 0, 5, 10, 15, 20, 25, 30, 40, 45, and 50% by stone powder sludge weight was selected. The flow test of the stone powder sludge samples with additional water content was carried out as per KS L 5105[10]. To investigate the density and strength properties of the AAC mixes with stone powder sludge, AAC specimens with different foam ratios of 0, 20, 40, 60, 80, 100, and 120% were produced. In addition, an AAC specimen with quartz sand containing a foam ratio of 120% was prepared to compare with AAC specimens with stone powder sludge. The mix proportions of the AAC mixes are given in Table 2.

The samples were mixed in a mechanical mixer. Cube molds at 100mm were cast to test the compressive strength and density, 100×200mm cylinder molds were cast to test the tensile strength, and 100×100×400mm beams were cast to test the flexural strength of the samples. The fresh samples were covered with polyethylene sheets to prevent evaporation. All of the specimens were kept at 20±2℃ for 3h and then cured at 80℃ for 7h. After autoclaving at 180℃, the samples were removed from the molds.

The density, compressive strength, tensile strength, and flexural strength of the AAC samples were tested at 24h, in accordance with KS F 2701[11], ASTM C 796[12], and ASTM C-348[13], respectively. Each value was the average of three samples. Once the samples were mechanically tested, some of the samples were finely ground to obtain powder. The X-ray diffraction patterns of these powders were obtained using a Bruker DS DISCOVER high resolution X-ray diffractometer.

Table 2. Mixture proportions

Mix.	Foam %	Water kg/m^3	C kg/m^3	AC kg/m^3	SL kg/m^3	AG kg/m^3	QS kg/m^3	SPS Kg/m^3
F00	0	520	556	56	20	33	-	882
F20	20	520	556	56	20	33	-	882
F40	40	520	556	56	20	33	-	882
F60	60	520	556	56	20	33	-	882
F80	80	520	556	56	20	33	-	882
F100	100	520	556	56	20	33	-	882
F120	120	520	556	56	20	33	-	882
Q120	120	520	556	56	20	33	882	-

3. Results and discussion

3.1 Fluidity variation of the SPS

Due to the high moisture content of stone powder sludge, it is difficult to mix the sludge with other materials. In previous studies[9,14], the stone powder sludge was used after drying and grinding processes. However, these processes are costly and are a significant obstacle to the use of stone powder sludge in the concrete industry. In this study, additional water was added to the stone powder sludge samples and the flow value was measured.

The variation in the flow of stone powder sludge for various added water content is shown in Figure 3 and 4. The test results demonstrate that the flow of stone powder sludge increases with an increase in the added water content. The flow value of stone powder sludge with added water content of 35% was about 230% higher than that of the stone powder sludge without additional water. This trend can also be seen in Figure 6, which shows the flow of stone powder sludge with 15% and 40% added water content. Here, 5% added water content caused an increase in the flow value of the stone powder sludge of about 5 to 40mm.

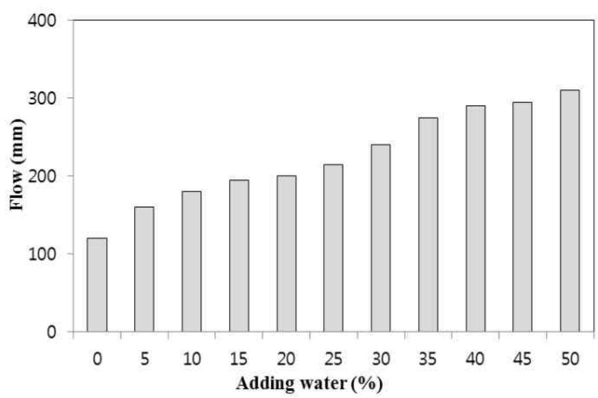

Figure 3. Flow versus added water content

(additional water 15%) (additional water 40%)

Figure 4. Flow of stone powder sludge

3.2 Density

The density of AAC samples was determined at 24h. The test results are given in Table 3 and shown in Figure 5, which shows the variation of density of the AAC samples with stone powder sludge at various foam ratios. The test results indicate that the density of AAC samples with stone powder sludge decreased as the foam ratio increased. The density of the F60 sample containing a foam ratio of 60% was about 33% lower than that of the F00 sample without foam. The densities of the F100 and F120 AAC samples with stone powder sludge at foam ratios of 100% and 120% were 0.75t/m^3 and 0.70t/m^3, respectively. For the same foam ratio of 120%, the density of the Q120 sample with quartz sand was similar to that of the F120 sample with stone powder sludge. Figure 6 shows the F60 and F120 AAC samples with stone powder sludge – where the foam ratios were 60% and 120%, respectively. As shown in Figure 6, the surface of the F120 sample had more pores than that of the F60 sample.

Table 3. Test results of AAC samples

Mix.	Density (t/m^3)	Compressive strength (MPa)	Tensile strength (MPa)	Flexural strength (MPa)
F00	1.50	19.0	1.48	2.30
F20	1.40	14.5	1.51	2.21
F40	1.20	14.2	1.30	2.00
F60	1.00	6.5	1.23	2.08
F80	0.90	7.5	0.84	1.31
F100	0.75	5.5	0.58	0.95
F120	0.70	4.3	0.60	0.47
Q120	0.64	3.2	0.44	0.66

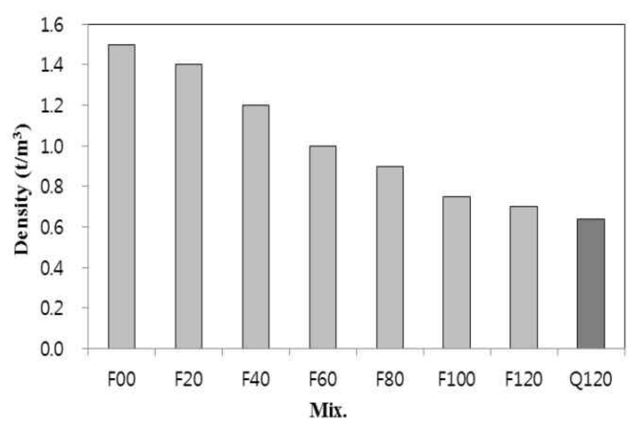

Figure 5. Density of AAC samples

Figure 6. AAC samples (left:F60, right:F120)

3.3 Compressive strength

The compressive strength test results are given in Table 3 and Figure 7. The test results demonstrate that the compressive strength of AAC samples with stone powder sludge decreased as the foam ratio increased. The compressive strength of the F20 and F40 AAC samples with foam ratios of 20% and 40% was about 24~26% lower than that of the F00 sample. In addition, the compressive strength of the F100 sample with a foam ratio of 100% was about 70% lower than that of the F00 sample. Note that for the same foam ratio of 120%, the compressive strength of the F120 sample with stone powder sludge was higher than that of the Q120 sample with quartz sand. Previous studies[15,16] have suggested that the utilization of finer quartz has the advantage of reducing the process time, and the degree of reaction of finer quartz was higher than that of coarser quartz after autoclaving. This increase in compressive strength might be attributed to the higher reaction activity by the finer particles of stone powder sludge compared to that of quartz sand after autoclaving. The compressive strength of the F120 AAC sample was about 33% higher than that of the Q120 sample. As shown in Figure 8, the correlation between the density and compressive strength of the mixture is obvious, regardless of the foam ratio.

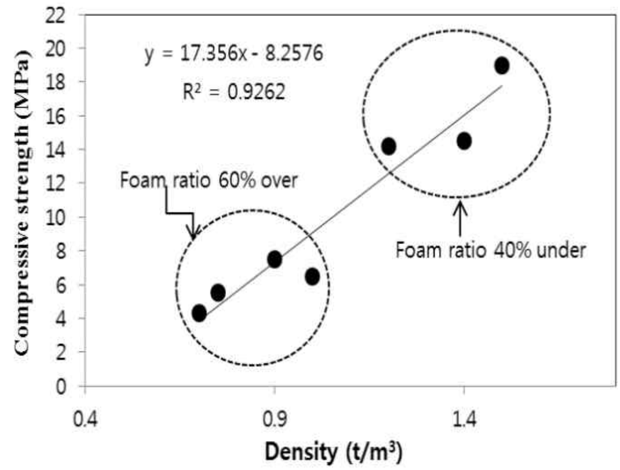

Figure 8. Relation between compressive strength and density of AAC samples

3.4 Tensile and flexural strength

The results of tensile and flexural strength tests are shown in Figures 9 and 10, demonstrating the variation in tensile strength and flexural strength with various foam ratios. As shown in Figure 9, for the AAC samples with stone powder sludge, the higher the foam ratio, the lower the tensile strength. The tensile strength of the F20 sample with a foam ratio of 20% was similar to that of the F00 sample with no foam. However, the tensile strength of the F120 sample with stone powder sludge with a foam ratio of 120% was much lower than that of the F00 sample.

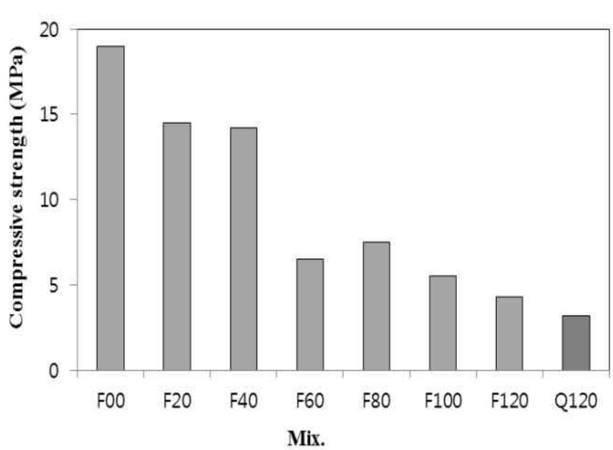

Figure 7. Compressive strength versus foam ratio

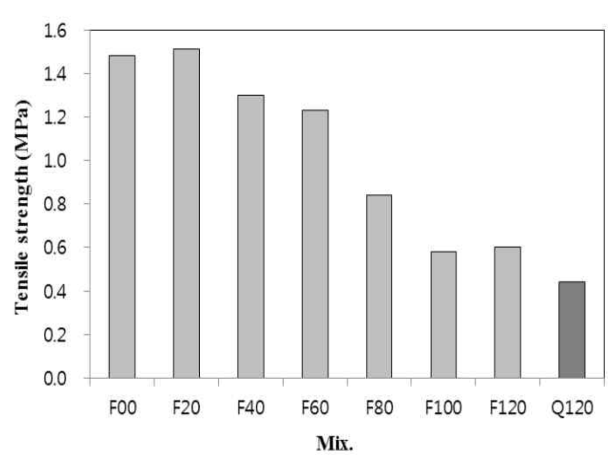

Figure 9. Tensile strength versus foam ratio

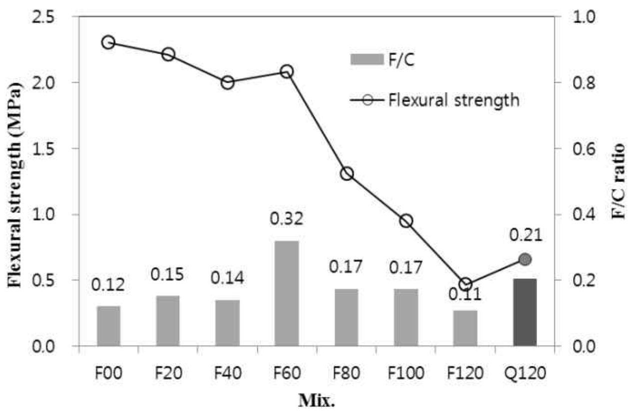

Figure 10. Flexural strength and F/C ratio

In addition, the tensile strength of the F120 sample with stone powder sludge was relatively higher than that of the Q120 sample with quartz sand having the same foam ratio of 120%. Figure 10 shows the variation of flexural strength and F/C ratio (Flexural strength / compressive strength). The flexural strength of AAC samples using stone powder sludge decreased with an increase in the foam ratio, and the F/C ratio of the AAC sample with stone powder sludge ranged from 11 to 32%.

3.5 X-ray diffraction

The test results are given in Figure 11, which presents the XRD patterns of the Q120 (sludge 0%) and F120 (sludge 100%) samples with same foam ratio of 120%, indicating the identified phases. For all XRD diagrams, sharp and intense peaks are shown around 2θ =26.6˚, implying quartz phases generally present in autoclaved aerated concrete. In addition, the XRD pattern of the F120 sample showed a strong peak at about 28.9˚, which is attributed to the presence of C-S-H phases composed of synthetic calcium silicate hydrate. As seen in Figure 11, a higher number of tobermorite peaks is shown for the F120 sample than for the Q120 sample, which may explain the slightly higher strength gain in the F120 sample with stone powder sludge. The additional strong peak at about 39.4˚ that is present in the XRD patterns of the sample can be attributed to the presence of calcite formed during the hydrothermal reaction.

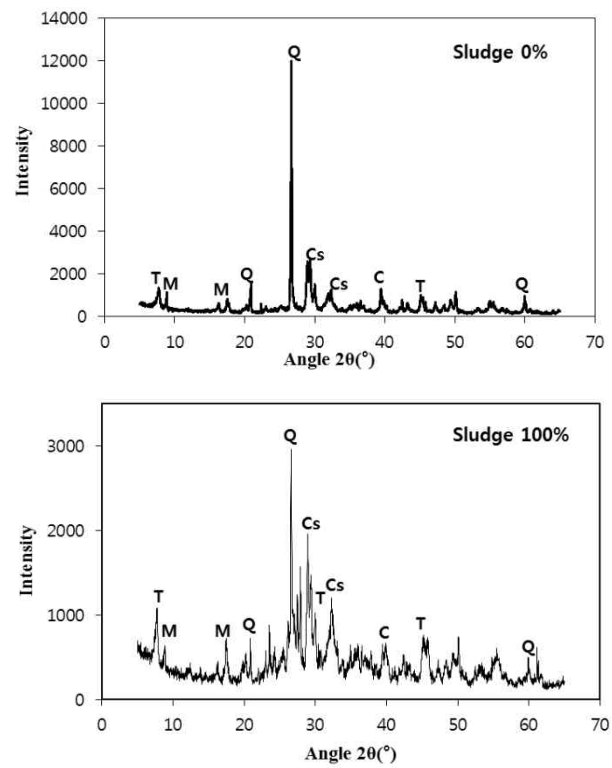

Figure 11. X-ray diffraction patterns of Q120(sludge 0%) and F120(sludge 100%) samples. (Q; quartz, C; calcite, Cs; calcium silicate hydrate, M; muscovite, T; tobermorite)

4. Conclusions

The following conclusions were obtained through this investigation:

1) In this study, the flow of stone powder sludge increased when there was an increase in the added water content. Here, a 5% added water content caused an increased in the flow value of the stone powder sludge of about 5 to 40mm.
2) The densities of the F100 and F120 AAC samples with stone powder sludge containing 100% and 120% foam ratios were 0.75t/m^3 and 0.70t/m^3, respectively. For the same foam ratio of 120%, the density of the Q120 sample with quartz sand

was similar to that of the F120 sample with stone powder sludge.

3) For the same foam ratio of 120%, the compressive strength of the F120 sample with stone powder sludge was higher than that of the Q120 sample with quartz sand. This increase in compressive strength might be attributed to the higher reaction activity by the finer particles of stone powder sludge compared to that of quartz sand after autoclaving.
4) For the AAC samples with stone powder sludge, the higher the foam ratio, the lower the tensile strength. The flexural strength of AAC samples using stone powder sludge decreased with an increase in the foam ratio, and the F/C ratio of the AAC sample with stone powder sludge ranged from 11 to 32%.
5) For all XRD diagrams, sharp and intense peaks are shown around 2θ =26.6˚, implying quartz phases are generally present in autoclaved aerated concrete. A higher number of tobermorite peaks is shown for the F120 sample than for the Q120 sample, which may explain the slightly higher strength gain in the F120 sample with stone powder sludge.
6) The results of this investigation suggest that the stone powder sludge can be effectively used in AAC mix to improve its reaction activity and mechanical strength.

Acknowledgements

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