Artur Łagosz[1], Paweł Szymański[2], Paweł Walczak[3]

[1] AGH University of Science and Technology
[2] H+H Polska Sp.z o.o, Poznan University of Technology
[3] H+H Polska Sp.z o.o., AGH University of Science and Technology

Influence of the fly ash type on properties of autoclaved aerated concrete

ABSTRACT: This paper is devoted to the relationship between properties of the siliceous fly ash used as an aggregate in production of autoclaved aerated concrete in PGS technology and its properties.

Tests were conducted on technological scale. Such technological measurements in this scale are not frequent and the influence of mix components, namely fly ash on the basic functional properties of AAC are seldom found in technical literature.

A series of AAC with similar binder content, constant composition and stable properties has been selected for experimental purposes.

Fly ash used as an aggregate came from various sources, and the composition and properties were a consequence of both the combustion of coal and co-firing with biomass.

The results show that, when the amount of binder and its properties are stable, the properties of ACC, especially compressive strength, are dependent on the properties of fly ash, which fulfils the function of aggregate. Linking such fly ash properties as specific surface area, fly ash water demand and content of unburned carbon may be the basis for a qualitative assessment of raw material in the manufacture of AAC.

KEY WORDS: Autoclaved aerated concrete, siliceous fly ash, PGS process technology

1. Introduction

Autoclaved aerated concrete (AAC) is a very modern building material. AAC has a very good properties: low density, low thermal conductivity and sufficient compressive strength.(1, 3, 4) Thanks to these properties autoclaved aerated concrete was the most popular building material in Poland in 2009. (2)

Sand, fly ash or mixture of them are basic raw materials for production AAC in Poland (1, 5). The siliceous fly ash is also used in Skawina (H+H Polska) plant, in the specific production technology – PGS. Cement is not used in this technology. Only mixture of quick lime, gypsum and fly ash are used as a binders.

Changes in quality of coal, temperature of burning and amount of co-combusted biomass influence on properties of the fly ash: fly ash water demand, content of unburned carbon (loos of ignition) and specific surface area. It has an impact on water to solid ratio. Different amount of water in the mass have an impact on properties of AAC, what was examined in this paper.

2. Experimental

Production technology of PGS is a specific technology and its diagram is shown on the Fig. 1. In this investigation w/s ratio is defined as water to solid components of AAC (quick lime, gypsum and all fly ash) ratio. The fly ash from one source is used as a binder to assure the stability of its properties. The siliceous fly ash from different sources was also used as aggregate.

Samples were taken of all AAC in the case of water content changes. Then both: fly ash used as aggregate and blocks of AAC were taken and examinated.

Specimens were taken during long period: from November 2009 to May 2010.

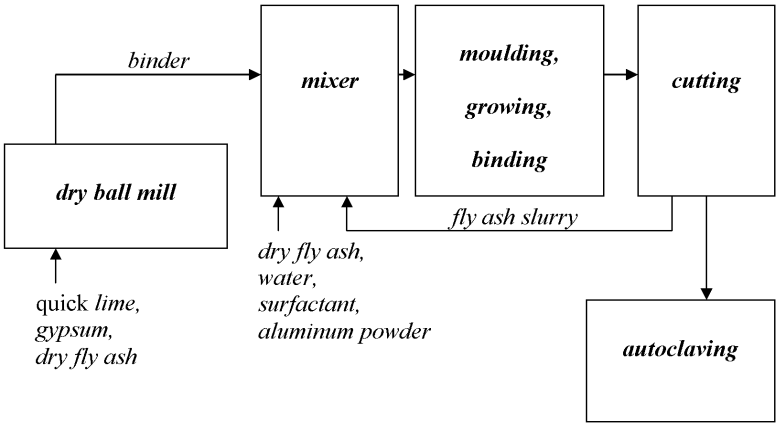

Fig 1. PGS process technology in plant Skawina.

Samples were examined in two laboratories: laboratory of H+H Polska and laboratory of Faculty of Materials Science and Ceramics (AGH; University of Science and Technology).

The test embraced 7 fly ash samples (FA1, FA2,…) and 7 AAC samples (AAC1, AAC2,…). All AAC specimens had very similar amount of binder (+/- 0.5% of quick lime used in 1m^3).

Table 1

PROPERTIES OF FLY ASH.

Property	Samples designation						
	FA1	FA2	FA3	FA4	FA5	FA6	FA7
water demand, %	30	25	24	32	25	34	40
loss of ignition, %	1.82	2.23	1.68	4.99	1.07	2.35	3.04
fineness, %	94.3	90.5	90.2	81.0	91.5	89.7	89.3
density, g/cm^3	2.41	2.44	2.23	2.38	2.19	2.36	2.38
specific surface area, cm^2/g	4400	4100	3700	3900	3300	4200	5000

Table 2

CORRECTIONS OF WATER AND AMOUNTS OF WATER ADDED TO THE MASS.

Water content	Samples designation						
	AAC1	AAC2	AAC3	AAC4	AAC5	AAC6	AAC7
water added to AAC mass, kg/m^3	289	281	261	274	275	288	292
Correction1) of water in 1m^3 ,kg	-11	-19	-39	-26	-25	-12	-8
w/s2) ratio	0.48	0.47	0.43	0.46	0.46	0.48	0.49

Remarks: 1) to maintain constant consistency of the mass
2) s = all solid components

Table 3

COMPRESSIVE STRENGTH AND DENSITY OF AAC

Property	Samples designation						
	AAC1	AAC2	AAC3	AAC4	AAC5	AAC6	AAC7
density, kg/m^3	605	630	635	640	590	630	600
compressive strength, N/mm^2	4.4	4.3	3.3	5.0	4.7	4.1	3.6

Table 4

WATER ABSORPTION OF AAC

Water absorption in gram after:	Samples designation						
	AAC1	AAC2	AAC3	AAC4	AAC5	AAC6	AAC7
10 min	190	174	168	186	209	163	193
30 min	153	138	125	153	164	132	158
90 min	128	119	129	133	134	117	136

Table 5

DRYING SHRINKAGE OF AAC

	Samples designation						
	AAC1	AAC2	AAC3	AAC4	AAC5	AAC6	AAC7
$\varepsilon_{cs,ref}$, mm/m	0.26	0.40	0.44	0.06	0.35	0.31	0.45
$\varepsilon_{cs,total,}$ mm/m	0.87	0.92	0.68	0.58	0.91	0.93	0.71

3. Results

The methods used for AAC samples study were in accordance with the standard PN-EN 771-4:2004/A1:2006 and with instruction of CEBET for fly ash.

3.1. Fly ash

Fly ash water demand, loss on ignition, fineness, density and specific surface area were determined. Loss of ignition was determined by heating fly ash samples at 950^{o}C for 1 h. Samples were cooled in exsiccator at room temperature and after that the loss of ignition were calculated. Fineness according to CEBET is defined as the amount of material which passes trough the sieve 63 μm, in percent, in our experiments. Fineness was measured using Alpine air jet sieve 200 LS-N. Specific surface area of fly ashe samples were determined in automatic Blaine air permeability apparatus.

All results are shown in the Table 1.

The samples of AAC blocks and of fly ash for their production were taken in the case when the corrections of water added to the mass were applied as is shown in Table 2. All data are registered automatically by computer, in which full information about proportioning are saved.

3.2. Samples of autoclaved aerated concrete

Compressive strength, density, freeze/thaw resistance, drying shrinkage, water adsorption of autoclaved aerated concrete were determined in this study.

Results of compressive strength and density are shown in the Table 3.

Freeze/thaw resistance was examined according to PN-EN 15304 and 16 cycles were applied. Dry samples test was used for loss of compressive strength determining. The highest decrease in compressive strength was 4,6%, and the highest increase was found in sample AAC6 equal 15,3%. The loss of mass were not higher than 1,2% for all samples.

Water absorption according the standard PN-EN 772-11:2002/Ap1:2005 was measured after 10, 30 and 90 min. Results are shown in the Table 4.

Drying shrinkage was determined according to PN-EN 680:2008 by measuring the length changes of specimens during moisture variations. Results are shown in the Table 5. $\varepsilon_{cs,ref}$ is a relative length change between 30% and 6% moisture content in mm/m, and $\varepsilon_{cs,total}$ is a total length change.

3.3. Microscopic examination

All fly ash samples were examined under the stereo microscope with the same zoom. The finest particles were found in sample FA3, the biggest particles in sample FA4 and the biggest particles size of unburnt coal in the sample FA7. The samples FA7 and FA3 are shown on Fig. 2.

Most of fly ashes and autoclaved aerated concrete samples were also examined under SEM. In all AAC samples hydrogarnet, amorphous C-S-H phase, poor crystalline C-S-H phase and tobermorite were found. The microanalysis EDS for phases were done. SEM of AAC samples are shown on the Fig. 3 and 4.

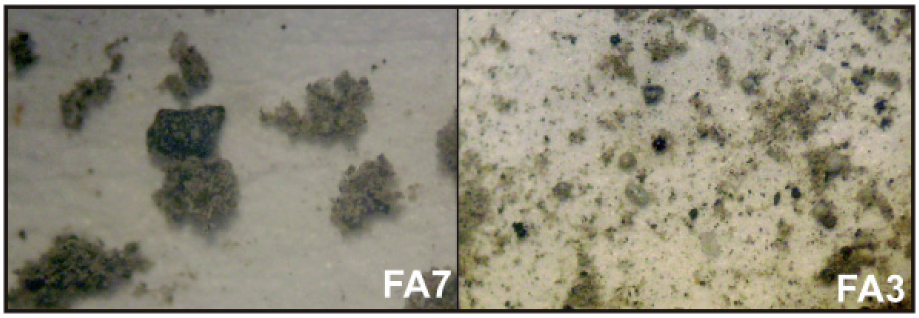

Fig. 2. Samples FA7 and FA3 under stereo microscope.

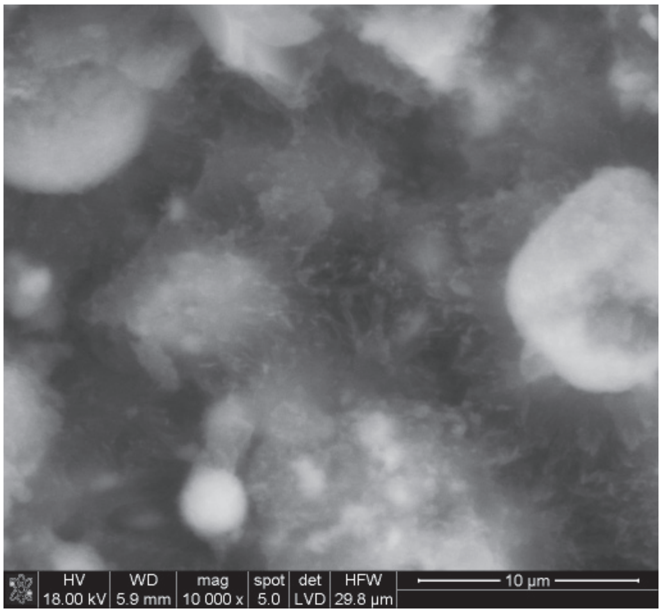

Fig. 3. SEM of AAC sample.

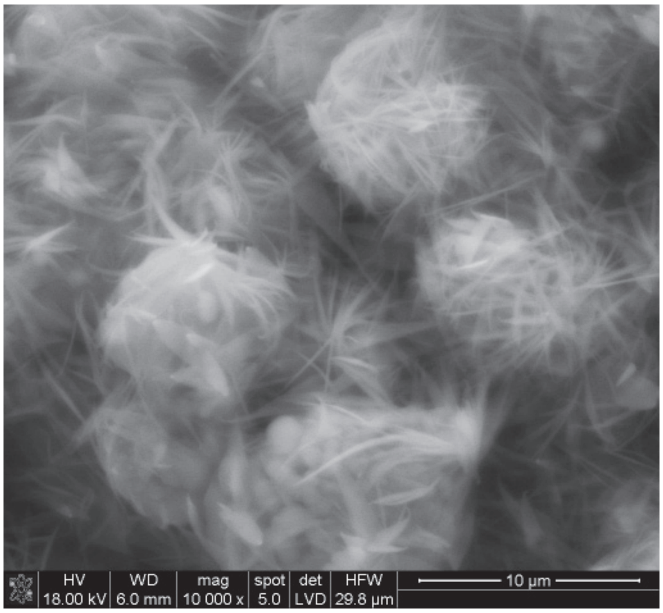

Fig. 4. Tobermorite in AAC sample.

4. Discussion

It is commonly know, that changes in water to solid ratio have impact on autoclaved aerated concrete properties. There are the properties of the fly ash which caused the changes in amounts of added water.

Relation between compressive strength and correction of added water (w/s) was observed and is shown on the Fig. 5. Differences in compressive strength were high. For example compressive strength of the sample AAC3 was 34% lower than of sample AAC4. Vertical lines embrace the AAC samples having the compressive strength higher than 4 N/mm^2, which was found in this study. The highest compressive strength was observed for AAC4 sample and SEM of this sample is shown on the Fig. 6.

As it was expected the compressive strength shown on the Fig. 4 depends on w/s ratio. The relation between specific surface area of fly ash and w/s ratio was also found, as is shown in Fig. 7.

Samples AAC4 and AAC5 have the highest compressive strength and the lowest the sample AAC3. However, as is shown on the Figure 7, all fly ashes which they contained (FA4, FA5, FA3) had similar specific surface area. The relation between specific surface area of fly ash and their water demand is shown on Fig. 8. Samples of fly ash FA5 and FA4 had various water demand and the similar situation was found for fly ashes FA3 and FA5. As it is evident from Fig. 8 it can not be correlated with differences in specific surface area of this samples. Moreover, samples FA2, FA5 and FA3 had very similar water demand and various specific surface area.

It is commonly know that unburnt coal is the main constituent of loss on ignition of siliceous fly ash, in most cases appearing as quick-coke with highly developed specific surface. Therefore

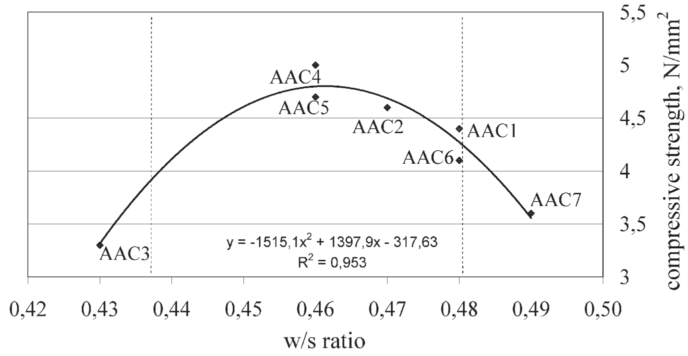

Fig. 5. Relation between compressive strength and w/s ratio of AAC.

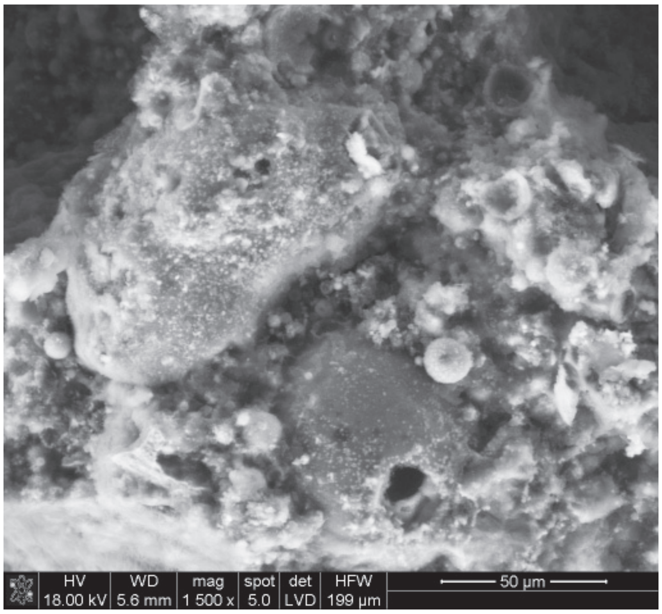

Fig. 6. SEM of AAC4 sample.

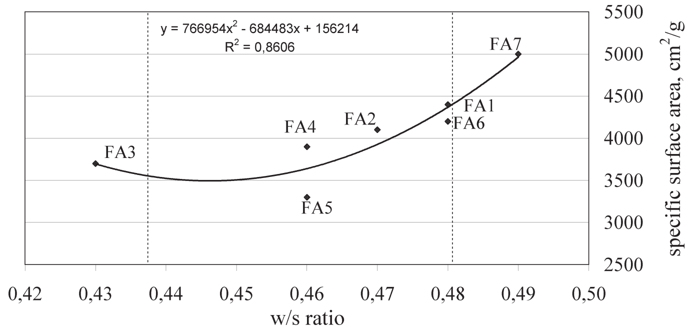

Fig. 7. Relation between specific surface area of fly ash and w/s ratio of AAC.

specific surface area and loss on ignition were compared (Fig. 9). Loss of ignition explains difference in specific surface area of the samples FA2, FA3 and FA5. For most samples relation is linear, but FA4 is an exception.

Others properties of fly ash and autoclaved aerated concrete shown, that samples AAC3 and AAC7 had the highest drying shrinkage (Table 5). In the case of AAC3, fly ash FA3 had very fine particles (Fig. 1) and in the case of AAC7, fly ash FA7 (Fig. 1) had coarse big particles of unburnt coal, what caused high drying shrinkage of AAC.

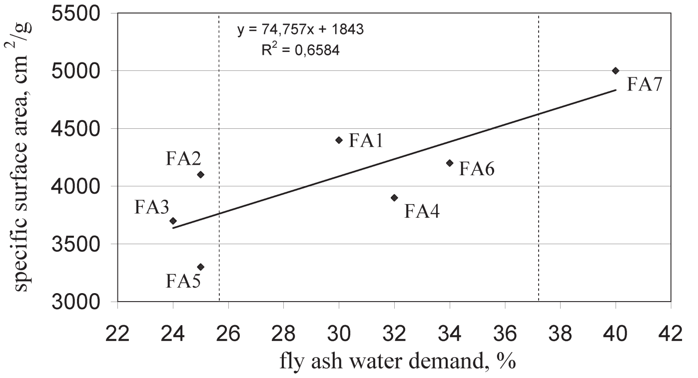

Fig. 8. Relation between specific surface area and fly ash water demand.

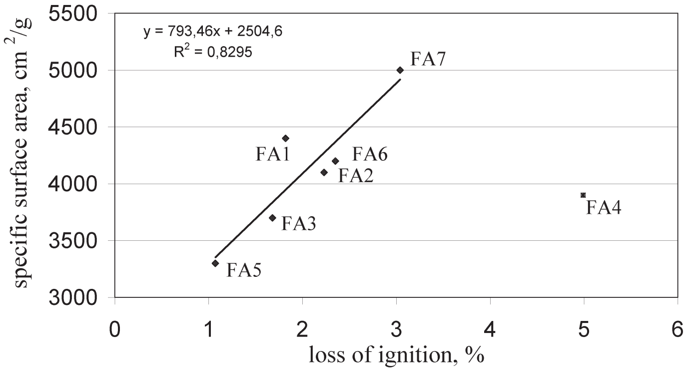

Fig. 9. Relation between specific surface area and loss of ignition.

5. Conclusion

On the basis of the experimental results the following conclusions can be drawn:

1. In PGS technology, when the properties of lime are stable, fly ash used as aggregate have the influence on autoclaved aerated concrete properties.
2. The necessity to add water which was the main change in production process had the fundamental influence on the properties of AAC and this change was caused by fly ash properties.
3. The influence of change fly ash source change (different power plant), on AAC durability was not found in this study.
4. Drying shrinkage depends principally on the fly ash fineness and coarse unburnt coal particles content in this fly ash.

References

[1] H. Jatymowicz, J. Siejko, G. Zapotoczna-Sytek. „Technologia autoklawizowanego betonu komórkowego", Wydawnictwo Arkady, Warszawa 1980.

[2] Materiały Budowlane, vol 452, s. 58, (2010).

[3] N. Narayanan, K. Ramamurthy, Cement and Concrete Composites , 22, pp. 321-329, (2000).

[4] A. Paprocki., "Betony komórkowe", Wydawnicto Arkady, Warszawa 1966.

[5] G. Zapotoczna-Sytek, AAC based on fly ash In the strategy of sustainble development. 4th International Conference on Autoclaved Aerated Concrete. Innovation and Development. London 8-9 September 2005, p. 257-264.