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Influence of material properties of input raw materials on microstructure of aerated concrete

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Abstract. One of the basic conditions of production of high quality products from aerated concrete is selection of appropriate input raw materials. Their material properties have crucial influence on the whole process of production of the aerated concrete products - from behavior of fresh mix of aerated concrete through setting to development of mineralogical phases during autoclaving. Properties of input materials, in particular their chemical composition, have considerable impact on the final properties of the product made of aerated concrete. This paper summarizes current knowledge from the research of microstructure of fly ash aerated concrete depending on chemical composition of the raw materials in the mix.

Introduction

Production of fly ash aerated concrete has positive environmental impact because major proportion of fly ash made as a by-product in power plants can be utilized. However, there is one disadvantage and it is the unstable chemical composition of fly ashes, which has a crucial impact on the final product. In particular the content of chemical compounds of Aluminum and high reactivity of silicon dioxide has an influence on formation of tobermorite at hydrothermal conditions.

The structure of tobermorite ($5CaO \cdot 6SiO_2 \cdot 5H_2O$) is orthosymetrical and consists of the centrally layer of Ca^{2+} octahedrons which is surrounded by continuous chains composed of silicate tetrahedrons. The layers are bonded to one another by an intermediate layer containing ions of Calcium and molecules of water. Small leaf-shaped crystals of this mineral are mutually well intergrown and form a compact skeletal structure of the autoclaved aerated concrete. [7]

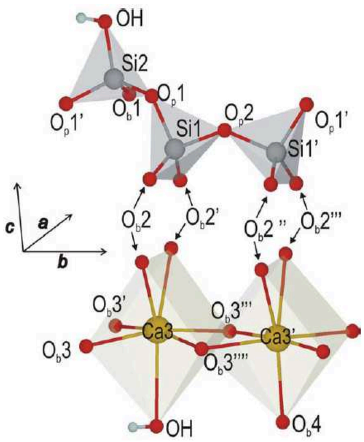

Fig.1 Structure of tobermorite [7]

Matsui et al. [1] in his work claims that tobermorite can be formed in two ways. The first one is a direct reaction of calcium hydroxide and silicon dioxide forming CSH gel, which crystallizes into tobermorite. It is a change in solid phase, when hemicrystals of tobermorite are formed from CSH gel due to supersaturation of the solution; the hemicrystals consequently recrystallize into crystalline tobermorite.

$Ca(OH)_2$, SiO_2, H_2O → CSH → tobermorite (1)

The second way is a reaction through katoite ($Ca_3Al_2(SiO_4)(OH)_8$), which belongs to the group of hydro-garnets. As a result of early formation of CSH products, dissolution of silica is slowed down and katoite is formed in a reaction of aluminum and calcium hydroxide. During the reaction, katoite is decomposed and tobermorite crystallizes from the solution.

Quartz, katoite, hydroxylellestadite, CSH → Ca^{2+}, Si^{4+}, Al^{3+},OH^- → tobermorite (2)

Influence of chemical compounds of aluminum and reactivity of silica on formation of tobermorite. There are several studies [1] [2] [3] [4] [5], claiming that content of Al in the mix of raw materials for aerated concrete and reactivity of silica influence final properties of aerated concrete. Aluminum slows down initial formation of CSH gel, however, later it accelerates metamorphism of CSH gel to tobermorite. The reason of initial limitation of CSH gel formation from silica and $Ca(OH)_2$ is the fact that Al reduces solubility of silica, which is caused by adsorption of aluminum on the surface of silica.

However, presence of aluminum in the mix has positive impact on crystallization of tobermorite and caused its earlier formation. In the mix of raw materials for aerated concrete with content of reactive silica Al accelerated the crystallization of tobermorite in the direction of the c-axis selectively. This effect is proportional to the amount of aluminum in the mix. As the amount of aluminum grows, the content of katoite increases, which contributes to formation of tobermorite through the reaction (2). Moreover, it limits metamorphism of tobermorite to xonotlite by extending thermal range in which tobermorite exists.

If reactive silica is used, CSH gel is relatively rapidly formed in early stages, which crystallizes to tobermorite only with difficulty in the reaction (1) and it can also slow down dissolution of silica and/or decomposition of the katoite in the reaction (2). Hence, CSH gel formed in the early stages of the reaction influences dissolubility of silica and katoite in later stages. One of the reasons can be the fact that CSH gel formed around the particles of silica forms barrier and prevents its dissolution.

However, if silica is present in less reactive form, its dissolution is put into later stages because of the influence of aluminum. It means that the reaction (1) is finished at early stages and the main process of formation of tobermorite is shifted into the reaction (2).

The above mentioned facts imply that if more reactive silica is used as a source of SiO_2, tobermorite crystallizes intensively in earlier stage of the autoclaving process, its formation is limited at later stages and the resulting aerated concrete contains CSH gel and katoite in addition to tobermorite. If less reactive silica is used, tobermorite is formed until the end of the reaction and its resulting amount is much higher than in the first case.

Method and results

In the experimental part, influence of chemical composition of fly ash on the content of tobermorite in aerated concrete was researched. Lime was used as a mortar component for manufacturing the test specimens of autoclaved fly ash aerated concrete. Siliceous component was represented by a mix of fly ash from high temperature combustion together with fly ash from fluidized bed combustion; calcium sulphate is the auxiliary component. Aluminum powder was used as gas making component. Chemical composition of samples of fly ash from high temperature and fluidized bed combustion was determined; the results are given in Table 1.

Table 1: Chemical composition of fly ash

[%]	SiO_2	Al_2O_3	Fe_2O_3	SO_3	CaO	MgO	K_2O	Na_2O	P_2O_5
High temperature fly ash	52.50	26.50	6.05	0.05	1.38	0.94	1.69	0.32	0.12
Fluidized bed combustion fly ash	34.99	17.74	6.27	7.92	23.70	1.03	1.22	0.43	0.23

Specimens of aerated concrete differ in the proportion of high temperature and fluidized bed combustion fly ash (Table 2); mix design of all specimens was identical as well as the conditions of autoclaving, which was carried out at the temperature of 174°C, pressure 0.8 – 1.3 MPa at the presence of wet steam.

Table 2: Proportions of fly ash in tested samples of aerated concrete.

	A	B	C
High temperature fly ash	100%	90%	80%
Fluidized bed combustion fly ash	0%	10%	20%

Specimens of aerated concrete were consequently analyzed by XRD, which determined mineralogical composition of aerated concrete. Comparing of XRD diffractograms of mix-designs A, B and C can also compare proportion of tobermorite in individual types of aerated concrete.

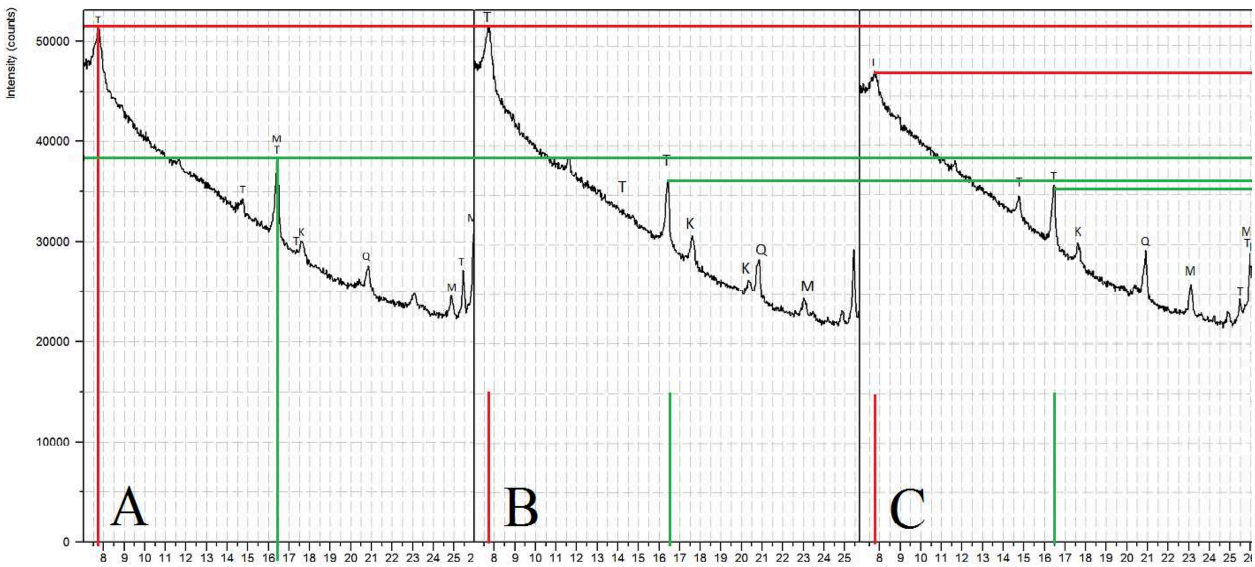

Fig. 2: XRD of aerated concrete specimens with various content of fluidized bed combustion fly ash A – 0% fluidized bed combustion fly ash, B – 10% fluidized bed combustion fly ash, C – 20% fluidized bed combustion fly ash

T – tobermorite, M – mullite, Q – quartz, K - katoite

The XRD diffractograms imply that as the proportion of fluidized bed combustion fly ash in the mix of raw materials for aerated concrete increases, the peaks representing tobermorite are reduced. If the content of Al_2O_3 in used types of fly ash is compared (Table 1), the conclusion is that chemical composition of fly ash produced during high temperature combustion and fluidized bed combustion differ, inter alia also as regards the content of Al_2O_3, which is by almost 9% lower in fluidized bed combustion fly ash. This result corresponds with the assumptions of the studies [1] [2] [5], that the content of aluminum in the mix of raw materials for aerated concrete has positive influence on crystallization of tobermorite. It was also confirmed that this effect is directly proportional to the amount of aluminum present in the mix.

Fly ash, in particular fly ash produced during high temperature combustion is created mostly by amorphous SiO_2, which is highly reactive. Hence, it can be assumed that crystallization of tobermorite was intensive even at the beginning of the hydrothermal reaction in particular in crystallization of CSH gel in the reaction (1) and at later stage it was not so intensive, which can be assumed from the content of katoite and amorphous CSH in all specimens of aerated concrete.

According to the literature search and the results of experimental verification, we can conclude that the utilization of fly ash with a high content of Al_2O_3 in the production of fly ash aerated concrete is very appropriate and results in a increased crystallization of tobermorite. Thus, we can assume even higher strength of porous concrete.

Summary

Based on the literature search of studies it can be stated that tobermorite can be formed in two ways. The first one is a reaction in solid phase from CSH gel, the second way is a reaction in the system solid – liquid phase through the mineral katoite. Many authors declare that content of aluminum in the mix has an influence on crystallization of tobermorite, which was confirmed in the experiment with various proportions of fly ash from high temperature and fluidized bed combustion; as the proportion of Al_2O_3 grows, the proportion of tobermorite in aerated concrete increases. Cristallinity of silica is another factor influencing resulting amount of tobermorite in aerated concrete. If a reactive siliceous component is used, like amorphous silica in fly ash, the reaction is intensive primarily at the beginning, it is only slow towards the end of the hydrothermal reaction.

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