Utilization of FBC ash in autoclaved aerated concrete technology

Vit Černý, Rostislav Drochytka

Abstract—There are still a lot of coal combustion products waiting for utilization in the Czech Republic. One of suitable building materials is fly ash aerated concrete. It is as a modern material combining high use value with environmental aspects of its production. Autoclaved aerated concrete is also one of the ways to use besides fly ashes from pulverized boilers fluidized bed combustion ashes. Significant advantage of the utilization of these CCPs from fluidized bed combustion is a saving of lime as the most expensive raw material for the production of aerated concrete. This paper deals about the possibility of fluidized fly ashes utilization in the technology of autoclaved aerated concrete, rheological properties of the mixture, the plastic strength, compressive strength and density of aerated concrete. Another topic of this paper is current state of use and legislative background of use of CCPs in the Czech Republic. Paper also verifies the autoclaving time influence on tobermoritic phase developments and to this related compressive strength of the fly ash aerated concrete.

Keywords—CCP, FBC ash, fly ash, tobermorite, legislation, aerated concrete, by-product.

I. INTRODUCTION

A. Origin of coal combustion products

In heating power plants, combusting pulverized coal (PC) are created solid minerals during combustion in a fully controlled process. The considered materials are ashes, i.e. the non-combustible part in coal, and in cases where flue-gas desulfurization equipment is installed, these are flue-gas desulfurization products. Most by-products originate in furnaces with granulating fireplaces, i.e. in the process of combustion with temperatures 1100 – 1400 °C. The process of combustion in a furnace with a granulating fireplace and the origination of energy by-products is shown in Fig. 1. [1]

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B. CCP and legislation

The previous paragraph referred to the coal combustion products. At this time this formulation is fairly widespread but from the viewpoint of legislation in the Czech Republic this concerns an amendment to the Act on Waste and progress in the direction of support for the use of materials that will not be evaluated in the waste regime. In particular, this concerns the criteria specified in Section 3, par. 5 of the Act:

A movable item originated during production where the primary objective is not the production or gathering this item, does not become waste but a by-product if:

a) originated as an integral part of the production,

b) its further use is ensured,

c) its further use is possible without further processing in a manner other than common production practice,

d) its further use is in accordance with special legal regulations 11a) and it will not lead to negative effects on the environment or human health. [4]

Conditions for the fulfillment of three criteria are:

The fulfillment of the last of these is the subject of stormy discussions. Very important is that the future use must not to harm the environment. The producer of the material must have a good Quality Management System, which ensure, that the final product will be environmental friendly.

For evaluation of the impact of the CCP on the environment are two ways available. If the producer produces more than 100 tones of CCP per year, must register it under the REACH directive (Registration Evaluation Authorization Restriction of Chemical substances).

In the Czech Republic were after the EU Directive...
1907/2006 (REACH Directive) registered and defined as chemical substances the following CCPs:
- Ashes (residues), coal – fly ash, boiler ash and slags from PC (Pulverized coal) boilers
- FBC Ash – Fluidized Bed Combustion Ash – fly ash and boiler ash from FBC boilers
- Ashes (residues), plant – ashes from biomass combustion
- Calcium sulphate – sulphates from wet FGD (Flue-gas desulfurization) process
- SDA Product – products of a semi-dry FGD process [2]

If the producer haven't registered your CCP under the REACH Directive must use other legislation terms. That means to look for harmonized European standards for his selected use according to the European system, Regulation (EU) No 305/2011 of the European Parliament and of the Council (Construction Products Regulation – CPR). If it doesn't exist, Authorized body can use prepared technical guide according to GO No. 163/2002 Coll.

C. CCP utilization in the Czech Republic

Research results show that fly ashes often adequately replace primary raw materials, although in many cases they actually improve the properties of final building products. Current methods for using flying ashes from traditional combustion are as follows:

II. USED RAW MATERIALS AND METHODS OF TESTING

The experiment was carried out in the plant producing aerated concrete and followed exactly the whole technological process of production of blocks from aerated concrete. Mix-design was based on real mix-designs. The aim was achieving characteristics of standardly produced aerated concrete P 2 – 480, i.e. compressive strength at least 2.0 N.mm⁻² and density up to 480 kg.m⁻³. For the experiment, fluidized bed combustion ash (FBC A) and two samples from pulverized coal boilers (PC A) with chemical composition stated in Table 1.

Table 1: Chemical composition of ash used

<table>
<thead>
<tr>
<th>Chemical analysis [%]</th>
<th>FBC A</th>
<th>PC A1</th>
<th>PC A2</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO₂</td>
<td>32.76</td>
<td>50.16</td>
<td>52.5</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>19.17</td>
<td>27.54</td>
<td>26.5</td>
</tr>
<tr>
<td>Fe₂O₃</td>
<td>8.52</td>
<td>13.08</td>
<td>6.05</td>
</tr>
<tr>
<td>FeO</td>
<td>0.47</td>
<td>3.96</td>
<td>1.04</td>
</tr>
<tr>
<td>CaO</td>
<td>19.4</td>
<td>2.51</td>
<td>1.38</td>
</tr>
<tr>
<td>total SO₃</td>
<td>8.21</td>
<td>0.38</td>
<td>0.27</td>
</tr>
<tr>
<td>sulphate SO₃</td>
<td>8.1</td>
<td>0.07</td>
<td>0.05</td>
</tr>
<tr>
<td>Na₂O</td>
<td>0.7</td>
<td>0.35</td>
<td>0.32</td>
</tr>
<tr>
<td>P₂O₅</td>
<td>0.72</td>
<td>0.19</td>
<td>0.12</td>
</tr>
<tr>
<td>loss on ignition</td>
<td>3.3</td>
<td>0.84</td>
<td>1.85</td>
</tr>
</tbody>
</table>

Further input materials were lime (binder), calcium sulphate (setting regulator), aluminium powder (gas making component), sludge from the waste fresh aerated concrete and water. Production test run in six phases, during which the mix-design was adjusted on the basis of behavior of aerated concrete mass.

Consequently, tests of physic-mechanical properties were carried out. Basic criteria were compressive strength and density, which are the decisive parameters of products from aerated concrete.

As additional was performed an experiment to investigate the effect of autoclaving time on fly-ash aerated concrete compressive strength and microstructure with selected mix-design. An experiment was carried out when the first set of specimens was autoclaved for standard time (11 hours) and with the second specimen set the isothermal holding time was extended by 2 hours during the autoclaving. The autoclaving run under standard conditions, so with temperature 174 °C, pressure 1 MPa and under presence of saturated water vapour. With both specimen sets the compressive strength was carried out together with scanning electron microscope (SEM) analysis.

III. RESULTS AND DISCUSSION

Test dose of fluidized bed combustion ash was 25 % by total amount of ashes in the mixture. The dose was based on calculation of theoretical mixing of ashes to comply
with requirements of standards describing chemical composition of ash for production of aerated concrete (CSN 72 2072-5 - ash from classic combustion of coal and CSN P 72 2081-4 fluidized bed combustion coal).

Mix-design adjusted on the basis of behavior of mass of aerated concrete. Table 2 gives composition of input materials in individual phases.

<table>
<thead>
<tr>
<th>Phase</th>
<th>Composition</th>
<th>Fluidized bed combustion ash</th>
<th>Lime</th>
<th>Calcium sulphate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phase1</td>
<td>25%</td>
<td>310 kg</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Phase2</td>
<td>25%</td>
<td>305 kg</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Phase3</td>
<td>25%</td>
<td>300 kg, 100 kg</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Phase4</td>
<td>20%</td>
<td>310 kg</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Phase5</td>
<td>20%</td>
<td>345 kg</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Phase6</td>
<td>20%</td>
<td>355 kg</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

In the next figures (Fig. 3, Fig. 4 and Fig. 5) are listed the values of plastic strength, compressive strength and density in individual phases. Plastic strength of the fresh aerated concrete is listed as a number of scale units of the plastometr. The optimum value is 460 - 500. Lower values cause the stickiness and higher cause the difficult cutting.

In the first phase, setting of aerated concrete was uncontrolled hardening and cutting was very difficult. Therefore, dose of lime was reduced in phase two. However, no major change occurred. In the third phase, energo-gypsum as setting regulator was added. Again, optimal properties were not achieved. Then, content of fluidized bed combustion ash was reduced to 20%.

In the fourth phase, compressive strength decreased to only 1.70 N.mm$^{-2}$, which does not correspond with strength class P2 – 480. Increasing dose of lime in the fifth phase brought slight improvement, however, optimal values were achieved only in the sixth phase, when compressive strength was 2.05 N.mm$^{-2}$ and density 475 kg.m$^{-3}$.

The mix-design from fourth phase was used to verify the effect of autoclaving time on compressive strength and microstructure of autoclaved aerated concrete. Once hardened the aerated concrete material by autoclaving the compressive strength test was carried out. The results are shown in Fig. 6.
According to compressive strength results it can be assumed that the extension of isothermal holding time during autoclaving results in higher compressive strength averagely by 0.8 MPa. This finding was further verified on aerated microstructure when photos were made on the scanning electron microscope. The photos are shown in Fig. 7 to Fig. 10.

At SEM 500x zoom not reacted fly-ash siliceous grains were recorded with aerated concrete autoclaved for standard time (Fig. 7). The reason is insufficient time of autoclaving when all components were not able to react completely. On photo of aerated concrete with extended autoclaving by 2 hours (Fig. 8) the fly-ash grains are almost imperceptible and relatively well developed tobermorite acicular crystals can be seen.

The SEM 1500x zoom is sufficient for good identification of aerated concrete crystalline structure. In Fig. 9 we can see in surrounding of place 1 idiomorphous crystals of calcite, at place 2 there is a colony of tobermorite acicular crystals in initial status of the development which gradually grow among calcite crystals. The extending of the isothermal holding time during autoclaving has according to the Fig. 10 a positive influence on tobermorite development. In the surroundings of place 1 we can see well developed tobermorite crystals, integrowing among themselves and thus forming a compact and firm structure of the aerated concrete. At place 2 there is the intercellular material formed by CSH gel.

**IV. CONCLUSIONS**

Use of fluidized bed combustion ash in autoclaved aerated concrete is very topical as production of this material rises. Advantage of considerable increasing of rheology is an important reason for using this raw material. Shortening
time before cutting and partial saving of lime are incidental economical parameters.

As a part of this paper, a series of tests was carried out implying that fluidized bed combustion ash can be used for technology of aerated concrete. When FBC ash is used in the proportion of 20% of total amount of ash and 355 kg of lime required properties of aerated concrete are achieved. Higher content of FBC ash causes uncontrolled hardening and difficulty cutting. Use of the FBC ash in the aerated concrete mixture will allow reduce hardening time before cutting by half. The aerated concrete is finished two hours earlier and production can be 15 % faster.

Ideal mix-design was achieved in Phase 6. Very good properties with lower dosage of lime had also mix-design from Phase 4 (20 % FCB, 310 kg lime), but the compressive strength was not sufficient. Therefore, an experiment was conducted where the autoclaving time was extended by two hours in order to increase the compressive strength. This requirement has been achieved and the compressive strength increased averagely by 0.8 MPa with the same density. This was verified in the SEM images and the samples with extended autoclaving time contained more developed tobermorite crystals.

REFERENCES

[1] Common interpretation EURELECTRIC /ECOBA: Classification of energy by-products according to the revised general directive on waste (2008/98/EC)
[4] Act No.185/2001 Coll. on waste and on the change and amendment to other laws, as amended