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Effect of firing temperature on the structure of the aggregate from sintered ashes

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Abstract

Production of artificial aggregate from ashes is worldwide known technology that uses up to 100% of ash in the mixture. There are known two types of aggregate. First is based on binders and known as cold-bonded. Second type of aggregate is produced by self-firing process that uses a content of combustible substances in the mixture. After ignition this fuel generates enough energy for the sintering process. The paper gives an account of the influence of parameters of ash and conditions of firing on the quality of ceramic body made from ash. Temperatures of 1050 °C, 1150 °C and 1200 °C were examined. The research focused on the structure of the ceramic body as well as its physic-mechanical parameters. The results show also that firing temperature is essential for forming the structure. An important indicator is the share of melt that form a solid ash body.

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Keywords: Artificial aggregate; fly ash; FCB ash; sintering; clinkering

1. Introduction

European and world trends in new technology development in the building industry make a sustained pressure on provision of production of quality light artificial aggregates, its application has a rising trend namely in advanced countries [1,2].

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Only Poland (in Central and Eastern Europe) reacted to this trend by construction of a factory for artificial aggregate production from sintered fly ash in Gdansk. The factory is equipped by license process equipment from Lytag, UK. However, the technology level of this production process is even older than the Corson technology [3].

The production technology of artificial aggregates made by burning are frequently operated in original format using quality black coal fly ash containing optimal amount of unburned residues and without necessary correction of the fuel substances in the mixture or the aggregate is burned by the external heat source [4].

There is no competition within this field in the world and thus the involved companies do not dedicate to development and innovations. On that ground the questions of artificial aggregates from sintered fly ash are relatively lowly explored. There are also only minimum scientific works dedicated to the process of production of fly ash body creation at burning. Therefore if we consider the possibility to restoration of the production in domestic conditions it is necessary not only to innovate the existing technology but also in particular to dedicate to study of reaction processes in solid phase and creation of fly ash aggregates [5].

2. Materials and methods

In the beginning, experimental activity was focused on the characterization of selected types of ashes, representing current production plants of the Czech Republic. There were following samples selected: fly ashes produced by high temperature combustion of brown coal as well as ashes from fluidized bed combustion of brown coal. It is necessary to repeat that high temperature ash are produced during combustion of minced coal at temperatures of 1200 – 1600 °C, desulphurization takes place after separators by using the lime solution. Fluidized bed combustion takes place at temperatures around 850 °C; desulphurization is located directly in the furnace by combustion of the lime together with coal.

Fly ashes from brown coal are represented by two samples (FA1, FA2). Ashes produced by fluidized bed combustion of brown coal are represented also by two samples (FBC1, FBC2).

2.1. Physico-mechanical and chemical parameters

Physic-mechanical and physic-chemical parameters are very important for basic evaluation of ashes. Following parameters were selected: loss on ignition, bulk density, specific surface area, rest on the sieve 0.063 mm and chemical composition. Following tables shows test results of individual samples of ashes.

Table 1. Physico-mechanical and physico-chemical parameters of tested ashes.

Samples	Loss on ignition (*%*)	Bulk density ($kg·m^{-3}$)	Rest on the sieve 0.063 mm (*%*)	Specific surface ($m^2·kg^{-1}$)
FA1	1.1	1110	42.9	299
FA2	1.9	1010	62.4	234
FBC1	2.1	640	33.7	361
FBC2	2.0	770	47.6	353

Table 2. Chemical composition of tested ashes.

Samples	SiO_2 (*%*)	Al_2O_3 (*%*)	Fe_2O_3 (*%*)	SO_3 (*%*)	CaO (*%*)
FA1	54.60	29.50	5.46	0.08	1.81
FA2	50.00	23.40	14.50	0.26	3.42
FBC1	27.60	17.50	5.63	7.57	30.40
FBC2	42.70	26.80	5.05	2.98	10.20

All samples fulfill the requirement of the standard CSN 72 2072-6 [6] for maximal loss on ignition (15%). Determination of bulk density shows that fly ash from high temperature combustion reach higher values than ash from fluidized bed combustion. All values of high temperature fly ash samples fulfill the requirements of the Standard CSN 72 2072-6 [6] for minimal value of shaken off bulk density 800 $kg·m^{-3}$.The finest ash is the FBC1. In most cases, specific surface area corresponds to results of granulometry of ash. Higher values show better quality of reaction in solid phase and formation of stronger structure of aggregate.

If we are evaluating the chemical composition of fly ashes it is obvious that FA2 may behave differently during firing than the other representatives of fly ashes due to increased Fe_2O_3 and with it associated high content of the minerals like hematite and maghemite. FBC ashes will be affected during annealing by a higher percentage of CaO and SO_3 contained in minerals such as the lime, calcite and anhydrite.

2.2. Firing tests

There were made specimens (20×20×100 mm) from tested ashes for better comparison of ash body quality. The ashes were mixed with some content of water for preparing these samples. It was found that FBC ash needs twice more water content as the fly ashes for the same consistency due to the character of the structure and chemical composition. González-Corrochano [7] suggests performing thermal pre-treatment of dry aggregate before sintering at lower temperature, than the sintering temperature, to avoid any unwanted explosions of the aggregate during sintering. This phenomenon was not observed in this research, possibly due to different composition of the used ashes.

Due to these findings, the pellets were dried 24 hours after the mixing. The temperature was set on 50 °C and the drying time on 6 hours in a dryer with forced air circulation. The firing tests followed. The temperature was set on 1050 °C, 1150 °C and 1200 °C, the growth rate of temperature was 600 °C per hour and the isothermal holding time was 10 minutes. It can better simulate the clinkering process in the technology furnace and showed the changes of structure of the ash body due to the different temperatures of the firing tests.

3. Test results and discussion

All tests have been performed in accordance with the Czech National Standards [6]. In the Fig. 1 you can see the results of density of the samples and in the Fig. 2 compressive strength and in the Fig. 3 water absorption of them.

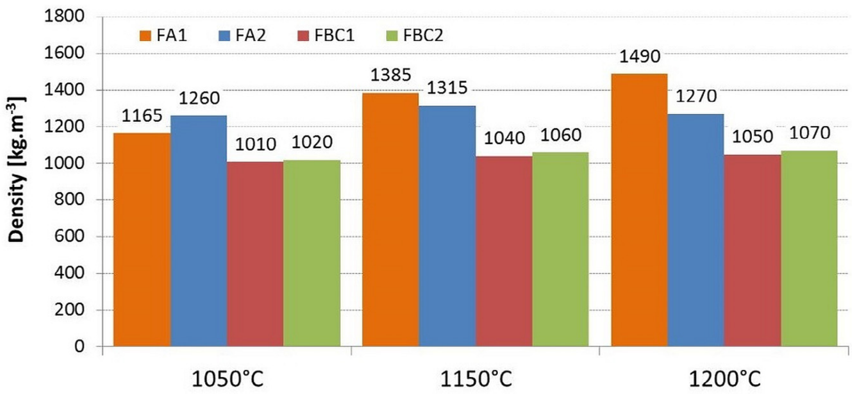

Fig. 1. Density of the fired specimens of tested ashes.

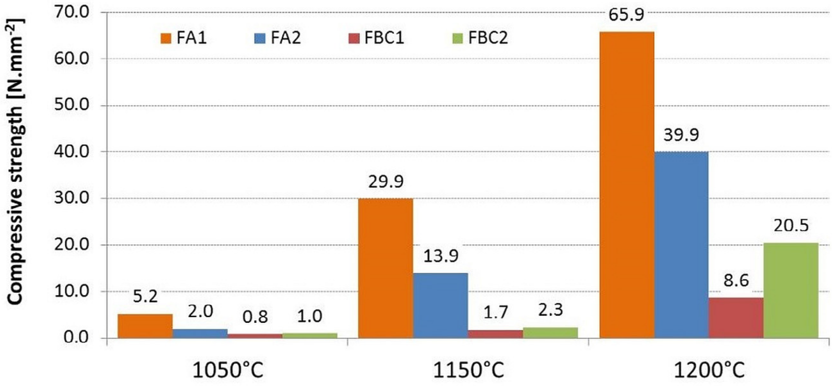

Fig. 2. Compressive strength of the fired specimens of tested ashes.

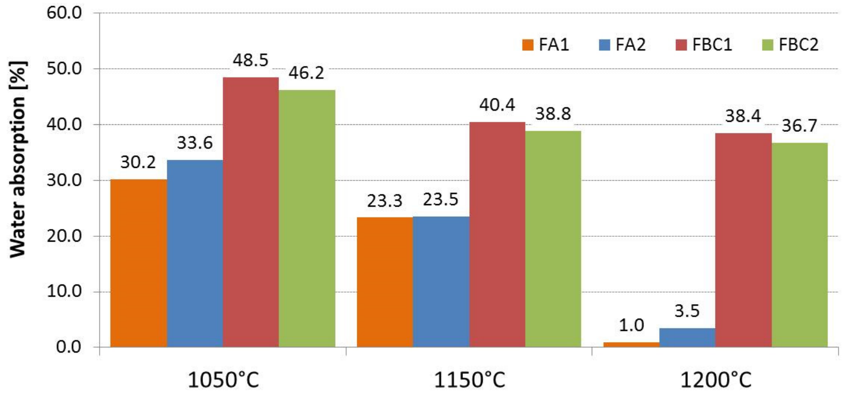

Fig. 3. Water absorption of the fired specimens of tested ashes.

The main knowledge gained through firing tests is the significance of influence of firing temperature. The temperature of 1050 °C is absolutely insufficient; specimens gain often only manipulation strengths. The strength of the specimens increased considerably at the temperature of 1150 °C. Increasing of the firing temperature by mere 50 °C brought another significant strengthening of the structure. If the influence of the type of fly ash on strength of test specimen is assessed, it is obvious that the method of coal combustion and proportions of SiO_2 and Fe_2O_3 in ash have significant influence. This is confirmed also by the results of determination of density and water absorbing capacity. Specimens fired at higher temperatures have higher density and lower water absorbing capacity. Influence of the type of ash is also apparent.

3.1. Evaluation of the structure of fired specimens

The main focus of the evaluation of firing temperature on the quality of the structure of ash body was the difference between specimens fired at temperatures 1150 °C and 1200 °C. Figures from SEM below show structure of specimens based on high temperature combustion or fluidized bed combustion ash.

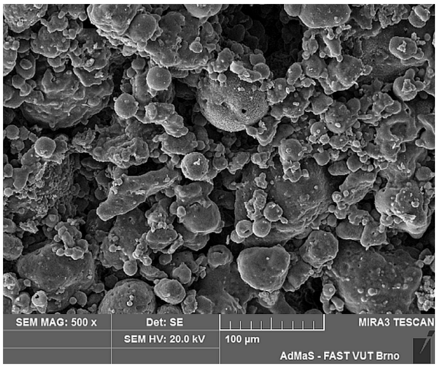

Fig. 4. Microstructure of ash body based on FA1 firing temperature 1150 °C.

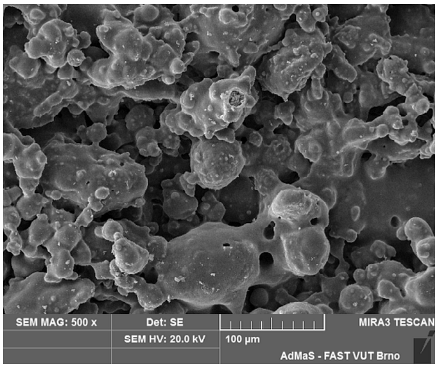

Fig. 5. Microstructure of ash body based on FA1 firing temperature 1200 °C.

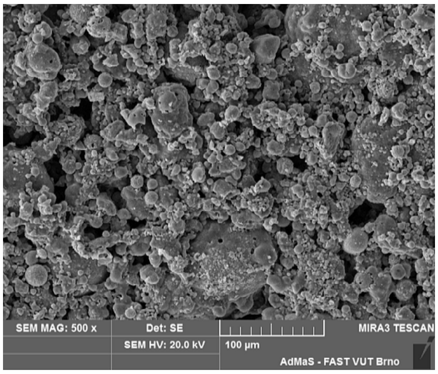

Fig. 6. Microstructure of ash body based on FA2 firing temperature 1150 °C.

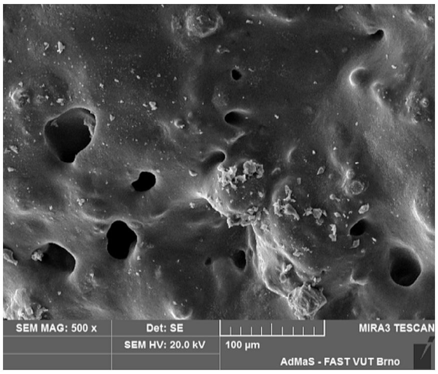

Fig. 7. Microstructure of ash body based on FA2 firing temperature 1200 °C.

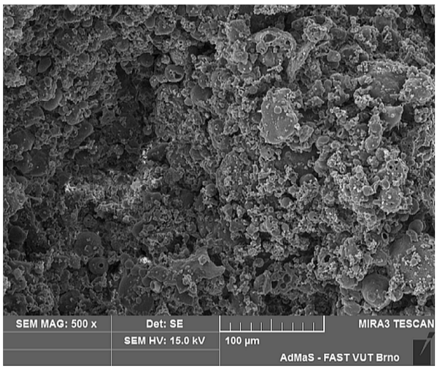

Fig. 8. Microstructure of ash body based on FBC1 firing temperature 1150 °C.

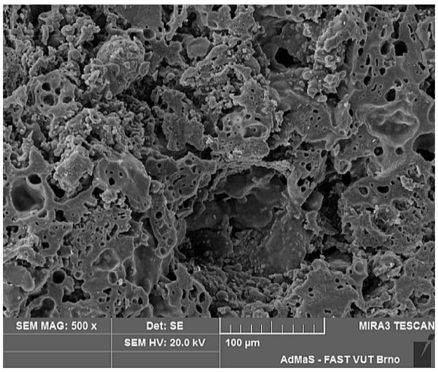

Fig. 9. Microstructure of ash body based on FBC1 firing temperature 1200 °C.

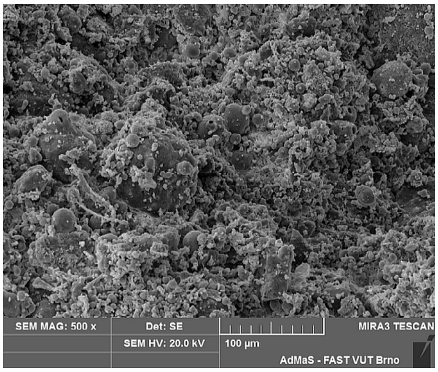

Fig. 10. Microstructure of ash body based on FBC2 firing temperature 1150 °C.

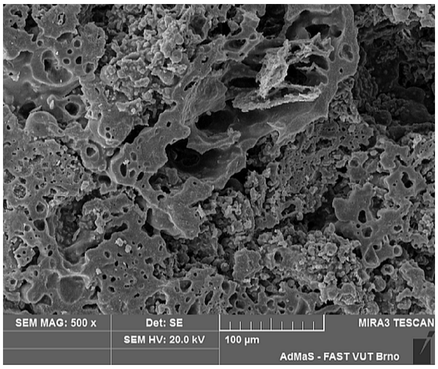

Fig. 11. Microstructure of ash body based on FBC2 firing temperature 1200 °C.

Evaluation of microstructure of specimens fired at temperatures 1150 °C and 1200 °C shows that even 50 °C difference is significant from the point of view of formation of strong structure. Grains of ash, which are only partly interconnected, are apparent in specimens fired at the temperature of 1150 °C. However, when the specimen was fired at the temperature of 1200 °C, grains of ash are interconnected into porous structure of ash body. Evaluation of the type of ash shows that ash with higher proportion of Fe_2O_3 or CaO has higher percentage of sintering and grains of ash disappeared totally.

Ilic, Cheeseman, Sollars, and Knight [8] in their research of sintered lignite coal (lower quality of brown coal) ash observed very similar results in the microstructure of their specimens in accordance to firing temperature. The appearance of specimens of sintered lignite coal ash sintered at 1130 °C was alike to our ash body based on FA1 at firing temperature of 1150 °C. This similarity continues at temperatures 1170 °C and 1190 °C in which the structure looks like specimens of ash body based on FA1 and FA2 sintered at 1200 °C. Those findings are confirmed also in Kourti and Cheeseman [9], who have had similar results in the microstructure of specimens made from lignite coal fly ash and recycled glass sintered at 1100 °C.

4. Conclusion

The paper shows influence of firing temperature on the quality of ash body. It can be stated that the temperature of 1050 °C is extremely inadequate for formation of strong structure. Increasing the temperature to 1150 °C brings considerable increase of strengths and reduction of water absorbing capacity, however, microscopic pictures show, that the structure is still not compact. The temperature of 1200 °C again increased the quality of the ash body considerably. This is apparent in the images from SEM, where formation of a strong structure can be observed. However, sintering of the surface and enclosing of the structure for escaping gas causes formation of large hollows within the structure and consequently reduce strength. Structure of the FBC1 ash also causes formation of many open pores, which weaken the structure.

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References

[1] S. Slabaugh, Ch. Swan, R. Malloy, Development and properties of Foamed synthetic Lightweight Aggregates, In World of Coal Ash Conference, Kentucky, 2007.

[2] H. Ecke, H. Sakanakura, T. Matsuto, N. Tanaka, A. Lagerkvist, State-of-the-art treatment processes for municipal solid waste incineration residues in Japan, Waste. Manage. Res. 18 (2000) 41–51.

[3] A. Mueller, S.N. Sokolova, V.I. Vereshagin, Characteristics of lightweight aggregates from primary and recycled raw materials, Constr. Build. Mater. 22 (2008) 703–712.

[4] R.N. Swamy, G.H. Lambert, The microstructure of Lytag aggregate, Int. J. Cement Comp. Lightweight Concrete 3 (1981) 273–282.

[5] T.Y. Lo, H. Cui, S.A. Memon, T. Noguchi, Manufacturing of sintered lightweight aggregate using high-carbon fly ash and its effect on the mechanical properties and microstructure of concrete, J. Clean. Prod. 112 (2016) 753–762.

[6] CSN 72 2072-6 Fly ash for building industry purposes - Part 6: Fly ash for the production of artificial aggregates by clinkering. Czech Standards Institute, Prague, 2013.

[7] B. González-Corrochano, J. Alonso-Azcárate, M. Rodas, Characterization of lightweight aggregates manufactured from washing aggregate sludge and fly ash, Resour. Conserv. Recy. 53 (2009) 571–581.

[8] M. Ilic, C. Cheeseman, C. Sollars, J. Knight, Mineralogy and microstructure of sintered lignite coal fly ash, Fuel 82 (2003) 331–336.

[9] I. Kourti, C.R. Cheeseman, Properties and microstructure of lightweight aggregate produced from lignite coal fly ash and recycled glass, Resour. Conserv. Recy. 54 (2010) 769–775.