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Possibilities of lightweight high strength concrete production from sintered fly ash aggregate

Vit Cerny[a]*, Magdalena Kocianova[a], Rostislav Drochytka[a]

[a]*Faculty of Civil engineering, Brno University of technology, Veveří 331/95, 602 00 Brno, Czech Republic*

Abstract

Heat power plants based on coal combustion are produced fly ash as a by-product. Fly ash is not only a by-product. It is due to its pozzolanic activity very useable as a fine additive to concrete in the building industry. It has not only environmental aspect, but also an economic. Potential of use of fly ash in cement concrete technology is only as an additive. But there is a technology of building material production, which use up to 100 % of fly ash in the "mixture". It is sintered artificial aggregate. It can be used for some filter layers, for lightweight flat roof, ceiling or for lightweight concrete composite. There can be made different strength classes of the concrete. It is possible also produce high-strength lightweight concrete reaching strength up to 55 MPa.
The paper is about possibilities of different types of fly ash for artificial sintered aggregate to achieve the parameters of lightweight high strength concrete. An interesting aspect of evaluating the quality of the composite is also synergistic interaction of aggregate joined to a cement paste.

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Keywords: artificial aggregate; fly ash; concrete; lightweight high strength concrete

* Corresponding author. Tel.: +420-541-148-061; fax: +420-549-245-147.
E-mail address: cerny.v@fce.vutbr.cz

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1. Introduction

Electricity produced via the burning of solid fuels is currently still one of the main sources of energy. However, this energy is not the only product created in power plants. During the process of electricity production, secondary energy products are created which are often of high quality and can be considered to be alternative resources. With regard to the large quantities of such materials that are produced, efforts have been made to search for potential ways of using them. At present, they are mostly utilised in the form of building materials. One of the suitable ways of exploiting their potential is their direct use in the form of an admixture or artificial aggregate for the production of concrete. [1, 2, 3]

In the Czech Republic in the 1980s, an artificial aggregate (Agloporit) was manufactured via self-firing at a high-capacity plant in Dětmarovice near Ostrava with the help of Corson technology. Production was stopped not only due to technical and economic considerations, but also for general organisational and conceptual reasons. The ash produced at the Dětmarovice power plant had very suitable qualitative features for use in the production of autoclaved aerated concrete and at large concrete plants as a partial replacement of cement.

Within the framework of research conducted with the purpose of renewing the production of sintered artificial aggregate in the Czech Republic, concrete test specimens made with artificial aggregate based on high-temperature ash from Dětmarovice power plant (black coal), Otrokovice heating plant (brown coal) and additionally brown-coal fly ash from Hodonín power station were produced in 2007. As in previous work by J. Adámek, [4, 5], the mixture was designed with a focus on very high quality connective mortar. In practice, this means the use of a higher proportion of natural 0-4 mm aggregate and the use of 4-8 mm and 8-16 mm fractions of artificial aggregate. With quality aggregate based on ash from Dětmarovice power plant (the resistance to crushing of the 8-16 mm fraction = 4.5 $N \cdot mm^{-2}$), a concrete cube strength of up to 54.7 $N \cdot mm^{-2}$ was achieved.

The submitted part of the experimental work is aimed at evaluating types of domestic high-temperature brown-coal ash with regard to their prospective use as long-term and stable sources for the production of sintered aggregate. Another goal is to verify the ability of concrete made with such types of ash to attain the parameters of LC 50/55 lightweight high-strength concrete.

2. The technique used for the production of artificial aggregate under experimental conditions

An example of the technique used to produce artificial aggregate can be presented using a horizontal sintering grate, 3 600 mm long and 400 mm wide, with a maximum batch height of 400 mm. A batch of pellets of the 8-16 mm fraction was used for the experiments. Horizontal movement is provided using an electric motor, which enables the final speed to be regulated via the timing of movement steps and thus mainly the duration of batch ignition. Firing is controlled via a set of vents which suck out the flue gases thanks to the ventilator, and convey new combustion air to the batch.

The following photographs show the process of firing in a horizontal furnace (Fig. 1), specifically with a batch based on high-temperature brown-coal ash. The batch is ignited by a 400 mm long natural gas-powered head. The batch is gradually moved in a standard manner and is fired for a period of 5 min. In order to achieve a smaller proportion of unfired grains and a decrease in the quantity of ignition gas, an ignition layer made from a mixture of coal and slag is applied to the batch. The content of combustible substances in the granulate of the ash mixture enables the self-firing of the aggregate after ignition without any other external source of heat. After the aggregate has reached the end of the grate and a temperature drop has been recorded, firing is considered to be complete. Forced air circulation is then used for cooling.

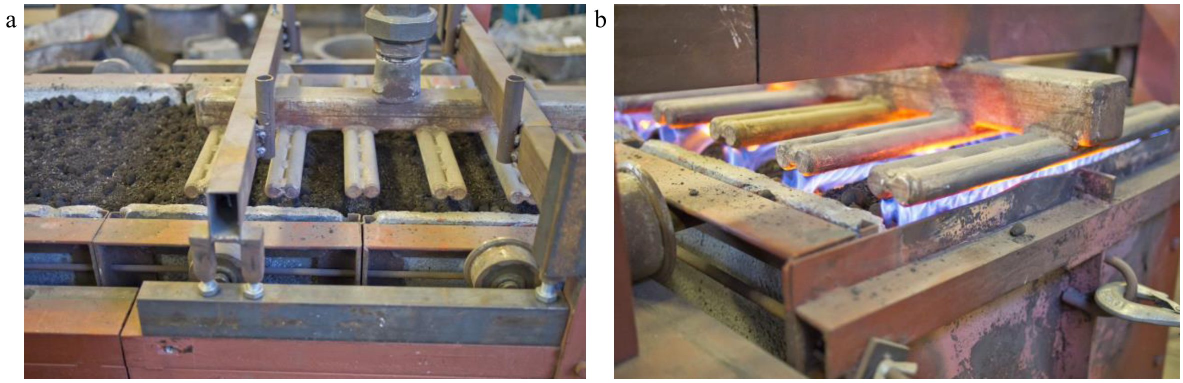

Fig. 1. (a) Horizontal furnace with ignition head; (b) Start of batch ignition.

After sufficient cooling of the batch, the aggregate can be handled further. In Fig. 2 we could see the burned aggregate with rest of the ignition layer. If smaller sinters are presents, their simple dissociation is recommended, which can take place without significant damage to the grains. Unfired grains may appear as the result of temperature shock when there is a rapid loss of heat. However, only a minimal proportion of the grains are of this type, and they can be eliminated with the use of a layer of solid fuel to maintain sufficient heat in the batch.

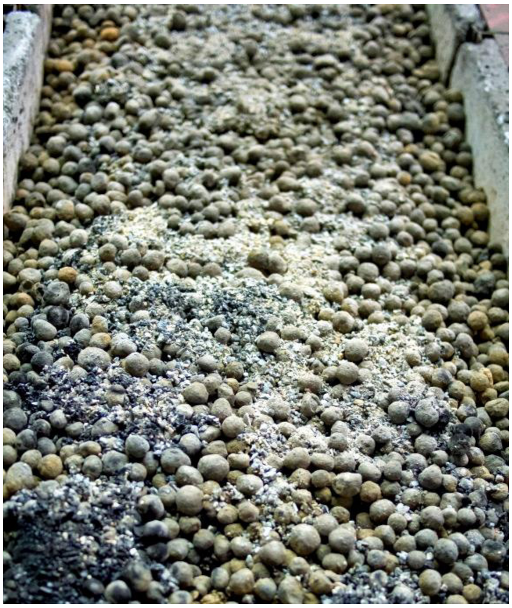

Fig. 2. Burned aggregate with rest of the ignition layer.

3. Properties of the tested kinds of ash and produced aggregate

After checking the suitability of domestic high-temperature brown-coal ash for the production of artificial aggregate, 4 types were selected that represent prospective sources of the material in the Czech Republic (Table 1).

Table 1. The main parameters of the tested ashes.

Sample	Loss on ignition [%]	Bulk density (tapped) [kg·m^{-3}]	Specific surface [m^2·kg^{-1}]	Residue on 0.045 mm sieve [%]	Chemical composition [%]				
					SiO_2	Al_2O_3	Fe_2O_3	SO_3	CaO
FA1	1.19	990	329	58.5	47.7	28.2	5.6	0.13	1.1
FA2	1.07	1110	299	53.1	54.6	29.5	5.5	0.10	1.8
FA3	1.15	1010	234	70.5	50.0	23.4	14.5	0.26	3.4
FA4	1.07	940	224	72.2	47.6	25.0	12.7	0.54	2.3

It is clear from the presented mechanical and physico-chemical parameters that ashes with a minimum content of unburnt ash are produced in the Czech Republic. Therefore, it will be necessary to mix the ash with milled coal so that an optimum combustible substance value of 8 wt% is achieved for self-firing. Also, ashes FA3 and FA4 exhibit greater roughness which is evaluated from the aspect of the residue on a 0.045 mm sieve and the specific surface. These two ashes also have a greater proportion of iron and lime which can cause the lowering of the melting temperature of the batch.

Aggregate was produced from the above-mentioned ashes and basic parameters were determined, there are: the bulk density of the dried aggregate, resistance against crushing, water absorption and amount of voids. The determined values are shown in the following Table 2.

Table 2. The main parameters of the tested aggregates.

Sample	Fraction [mm]	Bulk density of dry aggregate [kg·m^{-3}]	Resistance of aggregate to crushing [N·mm^{-2}]	Water absorption [%]	Amount of voids [%]
	1 – 4 mm	830	-	65	31
FA1	4 – 8 mm	1090	1.8	29	35
	8 – 16 mm	1170	4.0	20	48
	1 – 4 mm	870	-	57	40
FA2	4 – 8 mm	1050	1.8	34	39
	8 – 16 mm	1090	3.4	24	50
	1 – 4 mm	870	-	58	44
FA3	4 – 8 mm	1060	1.7	37	39
	8 – 16 mm	1140	3.2	26	34
	1 – 4 mm	850	-	65	39
FA4	4 – 8 mm	1060	1.3	33	37
	8 – 16 mm	1050	2.2	29	45

The determined results show the influence of the manner in which the individual fractions formed on their resultant properties. With regard to the fact that the batch consists of pellets of the 8-16 mm fraction, this fraction has the best properties because it has not disrupted surface and structure by crushing or shrinkage. The grains are compact with closed porosity. Thanks to this, they are firm with low water absorption. The grains of the 4-8 mm fraction are partially formed by shrunken grains from the original 8-16 mm fraction and partially by grains which were created by the crushing of sinters. It leads to the erosion of grains which can have lower strength and increased water absorption. The fine 1-4 mm fraction largely consists of fine particles with high water absorption and therefore it was removed. Due to its exclusion from the mixture, the resistance to crushing was not determined.

4. Testing of basic mixture for high-strength light concrete

Mixture was used to make specimens for testing to determine the possibility of using ash aggregate in the production of lightweight high-strength concrete. The test specimens were produced under laboratory conditions (paddle mixer, magnetic vibration table, 20°C, 50% relative humidity), taking the form of cubes with 150 mm long edges made with admixtures of ash and slag (see recipe in Table 3). The ash used in the mixture was always the same as the ash used for the production of sintered aggregate. Among others, results and findings presented in [6, 7] were taken into account for design of developed concrete. These studies state outcomes of research into the design of polymercement composites with agloporite content. Mechanical properties were determined for the samples.

Table 3. The main parameters of the tested aggregates.

Basic materials	Unit	Amount
Cement CEM I-42.5R	kg	450
Water	lit.	115
Sand 0-4 mm	kg	687
Wet sintered aggregate		
- 4-8 mm	kg	251
- 8-16 mm	kg	306
Admixture (ash/slag)	kg	75
Superplasticizer (Polycarboxylate ether)	kg	4.5

The artificial sintered aggregate was placed in water before mix preparation began (approx. 48 hours earlier). Thirty minutes before the start of mixing, it was placed on a perforated mat, allowing excessive water to drain off.

After 3, 7 and 28 days, the bulk density and compressive strength of the test specimens were determined. The resultant values are shown in the following graphs (Fig. 3, Fig. 4).

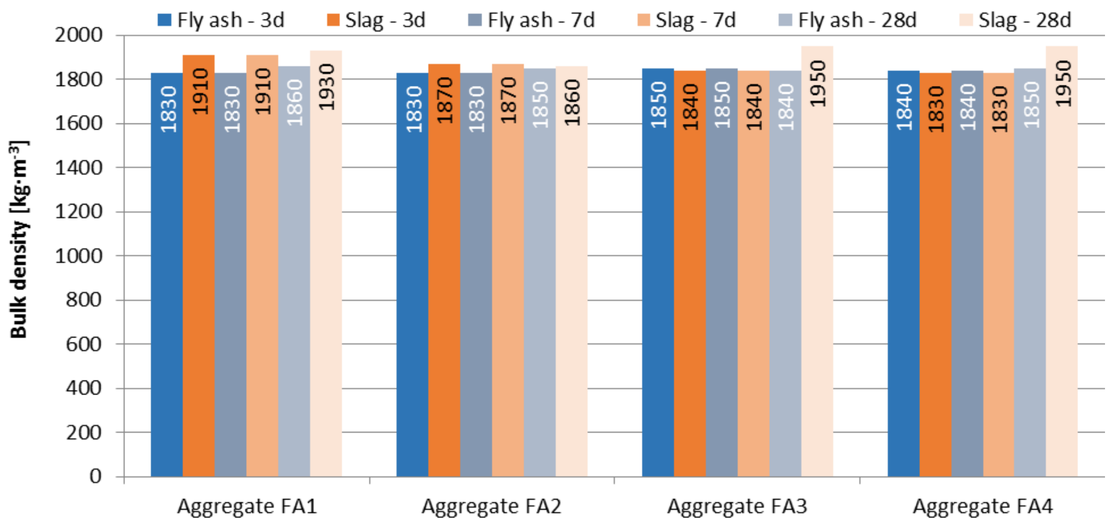

Fig. 3. Bulk densities of lightweight concretes after 3, 7 and 28 days.

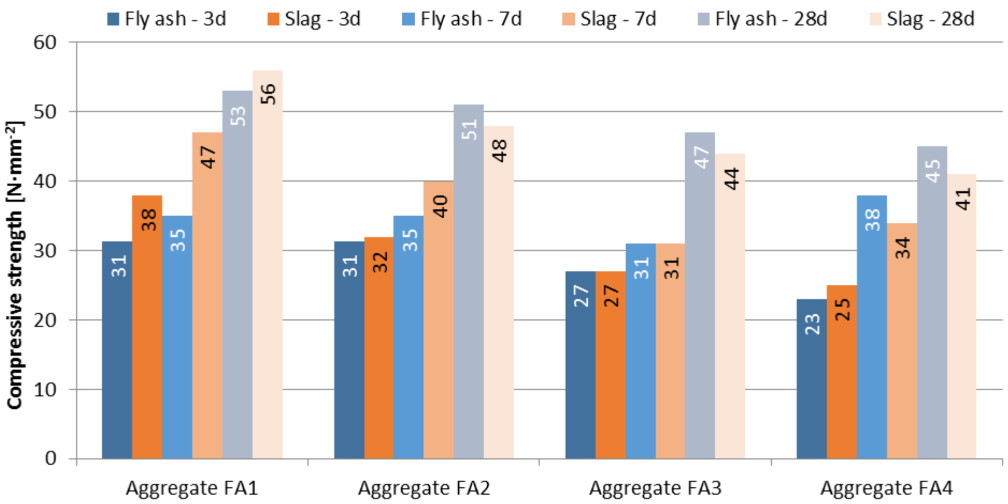

Fig. 4. Compressive strengths of lightweight concretes after 3, 7 and 28 days.

It is clear from the results shown from all the tested mixtures that the greatest 3, 7 and 28-day strengths are achieved by lightweight concretes with aggregates incorporating FA1 ash. The concretes using FA4 aggregate had the lowest strengths. Only mixture with the FA1 artificial ash aggregate and slag as admixture attained the 55 $N \cdot mm^{-2}$ strength needed to classify the lightweight concrete as LC 50/55 class according to the EN 206-1 Standard.

5. Interaction of aggregate joined to a cement paste

Referring to the results of scientific work J. Adámek [4, 5] was even done the basic validation of interaction artificial aggregates with cement paste. For illustration was chosen area with porous and compact shard with a higher proportion of black core. The macro photography of the selected area is shown on the following picture (Fig. 5 a), and photo taken by optical microscope is detailed on the further figures (Fig. 5 b – Fig. 6 b). An area with both types of aggregates is in Fig. 5, and the details of structure of the first and the second type are in further figures (Fig. 6 a, Fig. 6 b).

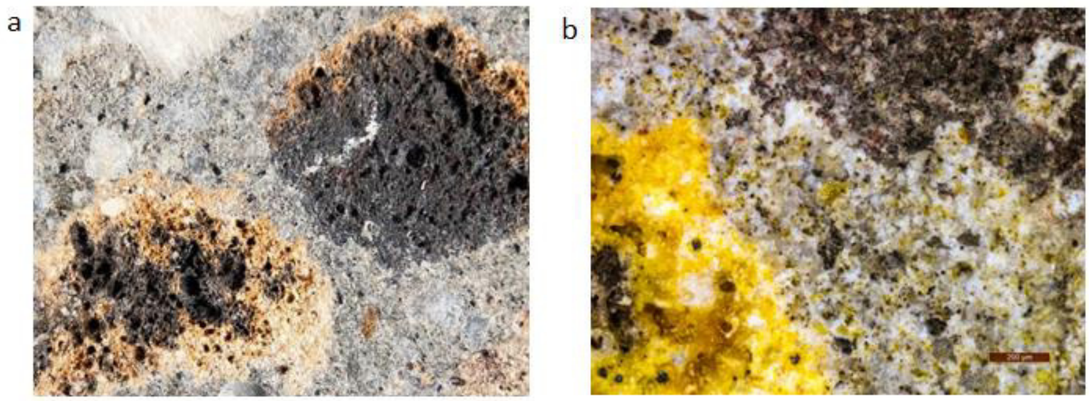

Fig. 5. (a) Macro photograph of agloporit-concrete sample; (b) Photograph from optical microscope (50x magnification).

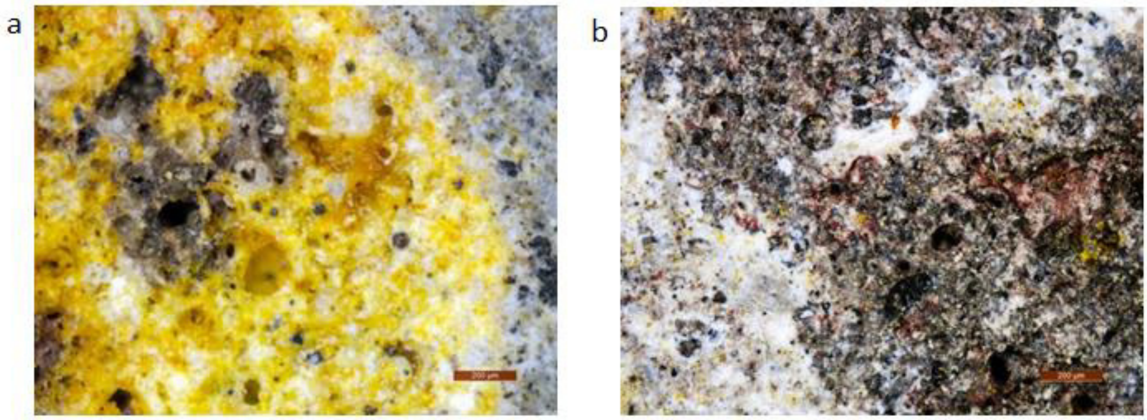

Fig. 6. (a) Photograph from optical microscope (50x magnification); (b) Photograph from optical microscope (50x magnification).

The images from the optical microscope show that the hydration products of the cement paste penetrate into the structure of open porosity of the aggregate. The presence of calcium was confirmed by the results of the EDAX analysis. Cement matrix thus increases its coherence with the aggregate and partially reduces influence of lower strength of porous grains on the strength of the composite. Closed pores remain without hydration products and concrete keeps low weight.

6. Conclusion

Pilot firings in a horizontal furnace showed that the best raw material for this technique is FA1 ash which was the finest of the tested ashes with the largest specific surface. Aggregate with a resistance to crushing of at least 2.3 $N \cdot mm^{-2}$ was thus obtained.

During the experiments with the production of high-strength lightweight concrete containing ash, in the majority of cases after 28 days of curing the measured aggregate strengths were below the value of 55 $N \cdot mm^{-2}$ needed for the inclusion of lightweight concretes in the LC 50/55 strength class. The required strength value of 55 $N \cdot mm^{-2}$ was measured when sintered FA1 ash aggregate was used. LC 50/55 could be attained in concretes containing artificial ash aggregates if cement and plasticizer dosages were increased. However, this raises the risk of increasing the bulk density beyond 2 000 $kg \cdot m^{-3}$, which is the limit value for lightweight concretes. Further research could be performed regarding the increase in strength which could be achieved, e.g. with an increased proportion of the 4-8 mm fraction.

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