Obtaining building materials from coal ash after separation of the residual carbon

Mihai Cruceru, Traian Alexandru Abagiu, Lucica Anghelescu, and Bogdan Diaconu

Abstract — There are 108 ash coal landfills In Romania occupying an area of 2823 ha, the volume of stored coal ash representing several thousand million cubic meters. These landfills, even if they were closed, continue to impact negatively the environment by: modifying the composition and quality of the soil in the vicinity due to deposition of ash particles, pollution of ground water by infiltration, accumulation of heavy metals in local flora and damage to human health. Although various measures to diminish the environmental impact are available, the use of coal ash as a potential raw material could be considered as a better solution.

The coal ash presents a valuable oxide composition, a suitable fine grain size, which is a major advantage in the production of building materials by excluding the energy required for grinding.

This paper presents the main data regarding building materials manufacturing by using coal ash as substitute by up to 50% of raw materials which are obtained usually by destructive action on superficial soil layers.

Keywords— coal ash, building materials, molding technologies.

I. INTRODUCTION

ROMANIA has the largest and most stable power system in the Balkans area and it is synchronously interconnected to the European grid. The lignite-fired power plants proved to be crucial for covering the Romanian electricity consumption especially during winters and extended periods of drought. They also contributed with a significant share to the stability of the power system throughout the entire region. During the latest years this role has become increasingly prominent [1]. Although Romania has developed electricity generation technologies, the lignite-fired power plants still play a significant role, covering approximately 25% from electricity consumption in Romania. For many years in the past, the lignite-fired power plants used to cover over 40% of power consumption [2].

The major drawback is the generation of large amounts of coal ash. The coal ash storage raises concerns in terms of economy and environment (e.g. a 330 MW pulverized fuel unit consumes around 1,000 ton/h of coal and generates ca. 400 tons of ash and slag at the same time). It is true that a part of fly ash that may be reintroduced into the economic circuit by using it in cement industry. However, only 5-8% of the coal ash generated is used currently in Romania, the rest being stored in large landfills, usually built through major changes of the natural landscape and containing tens or even hundreds of millions tones of ash [3] .. [9]. Therefore, several actions are being taken in Romania in order to decrease the amount of ash landfilled, and to raise awareness concerning the need to revise legal provisions (e.g. actually the use of ash in road construction is still banned, without distinguishing between fly ash (chemically active ash that can generate important secondary phenomena by hydration processes) and bottom ash (chemically inert and with physical-chemical properties very close to those of natural granular aggregates, like sand) [5] .. [12].

The University "Constantin Brancusi“ of Targu Jiu (UCB) is actively involved since 2011 in an research effort to detect efficient directions to recover the coal ash generated by thermal power plants, prevalent in the Oltenia industrial area, particularly for using them as alternative raw material in the building industry [3] .. [7]. Therefore, UCB continue and widens the efforts to recover coal ash through its participation in the European Project CHARPHITE consortium under the scope of the “Third ERA-MIN Joint Call (2015) on Sustainable Supply of Raw Materials in Europe.

The main goal of the project is to use the carbonaceous solid residue (char) from Oltenia bottom ash as substitution material for natural graphite in cutting-edge energy technologies, such as catalysts for electrochemical reactions in cell batteries or hydrogen and oxygen production by water electrolysis [13].

The UCB’s research team contribution in this project mainly aims the separation of the char from fresh and landfilled

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bottom ash, and further assessment and utilization of the "char-free" coal ash.

II. Methodology and procedures

A. The fine coal ash

In a previous paper [14], we described in detail how we effectively separated the carbonaceous solid residue from coal ash by physical methods based on the determined characteristics: size distribution and density differences. The sieving trials showed that almost 84 % of the coal ash passes the 0.5 mm sieve, these fine fractions of coal ash having a negligible content of fixed carbon

The fine coal ash is similar to natural clay-limestone quartz sands extracted and commonly used in many geographical areas of Romania for preparation of concrete with hydraulic hardening. Specific feature is the lower bulk density of approx. 25-30% compared to sand (easy aggregate according to EN 1097-3), where the ability to obtain lightweight concrete according to the EN 206-1 classification standard. In terms of chemical composition of ash from thermal power plant of Ceplea Valley it belongs to polynary oxide system SiO_2 - Al_2O_3 - Fe_2O_3 - CaO, being in this respect quite similar to feldspathic limestone partially calcined clays (sub-burned firebrick): SiO_2 (40-50%), Al_2O_3 (16-21%), Fe_2O_3 (8-9%), CaO (9-14%), Na_2O+K_2O (1,5-3%), P.C. (5-12%) [15], [16].

We tested several methods to find viable applications for the ash fraction with dimension less than 0.5 mm, obtained after sieving. This fraction is majority of weight mass: it contains virtually no unburned coal and consequently can be used as a substitute for sand.

In the experimental work, the fine fraction of ash was used as raw material to obtain building materials through application of two types of technologies: ceramic bonding (products pressed and burned) and hydraulic bonding (concrete based on hydraulic binder).

B. Manufacturing technology of ceramic bonding products

We studied the reusability of the ash fraction below 0.5 mm by considering it as degreaser component in clay-based plastic and semi-plastic mixtures. We used fat clay as plastic component and ceramic binder. The fat clay was provided by Rosia Jiu lignite open pit, being an industrial waste resulted from excavations.

We studied the properties of some different mixtures, which are shown in Table 1.

We homogenized the mixtures manually and the test samples were obtained by pressing the mixture in metallic molds, forming cylinders with a diameter of 50 mm and a height of 50 mm.

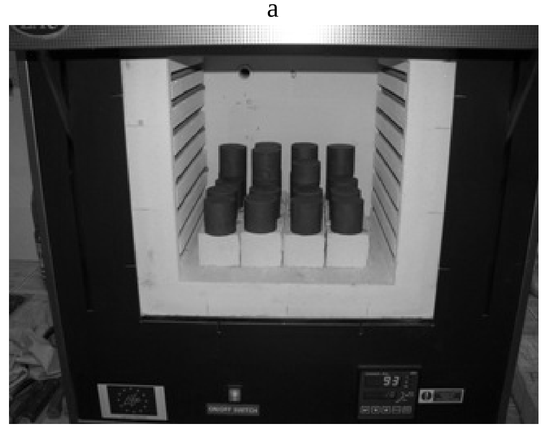
A nominal pressure of 51 MPa was applied, in two stages, with aeration at 5 MPa. Twelve test samples were prepared from each mixture.

We kept the test samples at room temperature for 24 hours after manufacturing. The test samples were dried in a thermostatic electric oven at 110 $^oC \pm 2$ ^oC, the maximum temperature being maintained for 10 hours. After drying, the samples were fired in an electrical furnace at temperatures of 985 ^oC and 1000 ^oC, by applying a growing gradient of temperature of 3 ^oC/min, the maximum temperature being maintained for 3 hours (Fig. 1).

Table 1. Compositions of the molding mixtures

Mixture	Ratio (%, weight)	
No.	Fat clay	Fine ash <0,5 mm
1	100	0
2	90	10
3	88	12
4	85	15
5	82	18
6	80	20
7	70	30
8	65	35
9	60	40
10	55	45
11	50	50

a



b

Fig. 1.Thermal treatment of cylinders (a – drying, b – burning)

After firing, the samples were tested in laboratory to determine the physical characteristics: apparent density, water absorption capacity, open porosity, compression strength (Fig. 2).

C. Manufacturing technology of hydraulic bonding products

We studied the hydraulic bonded materials manufactured from two lightweight concrete compositions that contain fine ash sampled from Ceplea Valley landfill (CET Turceni) as fine granular aggregate. To ensure optimum concrete mix grain size, the slag resulting from lignite burning in fluidized bed within the boilers from UATA Motru was used as granular aggregate. This slag is a residue characterized by lack of unburned coal, a bulk density of 0.45 - 0.55 g/cm3 and a main grain size more than 1 mm (10% 4-8 mm). One of the mixtures contains expanded perlite, granular synthetic ultra-light aggregate, characterized by a bulk density of 0.10 to 0.12 g/cm3 and a grain size distribution between 0-3 mm.

When we set out the compositions of concrete we considered the high melting point of the coal ash (over 1100 0C). We used as hydraulic binder an aluminum-calcium cement (refractory cement) containing 50% Al_2O_3, type ISTRA 50 produced by Heidelberg group - Croatia.

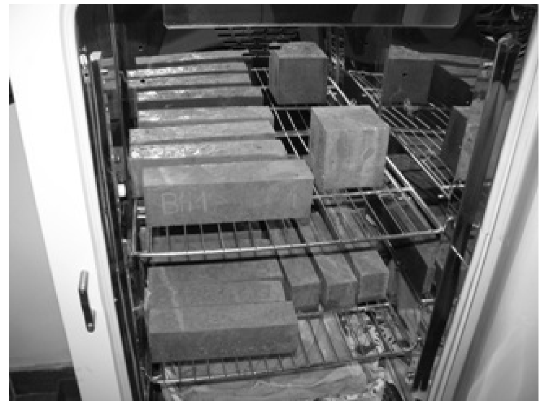
Table .2. Components dosage in fine ash concrete Ceplea

Sample	Components (%, weight)			
	Aluminium cement	Ash <0,5 mm	Slag Motru	Expanded Perlite
Bh 1	30	30	40	0
Bh 2	40	32.5	17.5	10

Experimental batches of concrete were manually homogenized, the raw concrete being poured into metallic molds with dimensions of 230 x 64 x 54 mm (B type prisms, according to EN 1402 - Standard for tests on refractory concrete). Compaction of concrete has been carried out by vibrating the test samples using a standard laboratory vibrating table (frequency 50 Hz, amplitude 0.5 mm).

After compaction, the prisms were maintained (coated with polyethylene) at ambient temperature for 24 hours and then they were peeled and maintained for additional 24 hours in a thermostatic room at 20 0 C ± 1 ^{o}C and 95% humidity. The prisms were dried in an electric oven with exhauster at 110 ^{o}C ± 2 ^{o}C with a 10 hours holding time at the maximum temperature. The prisms were burned in the laboratory electrical furnace at a temperature of 1100 ^{o}C, by heating them at a rate of 3.5 ^{o}C/min, the maximum temperature being maintained for 4 hours (Fig. 2).

The dried and burned prisms were tested in laboratory to determine the physical characteristics: apparent density, water absorption capacity, open porosity, and compression strength.



a

b

Fig. 2. Thermal treatment of prisms (a – drying, b – burning

III. Results and discussions

For applications with the role of degreasing - technologies for ceramic bonded products (pressed and burned bricks), fine ash from thermal power provides interesting variations of characteristics such as decreasing the density and increasing the water absorption capacity and open porosity. Such effects may generate a significant increase of the capacity for thermal and acoustic insulation. Specific variation of these parameters depending on the fine ash content and the burning temperature are shown as graphically in Fig. 3 ... 6.

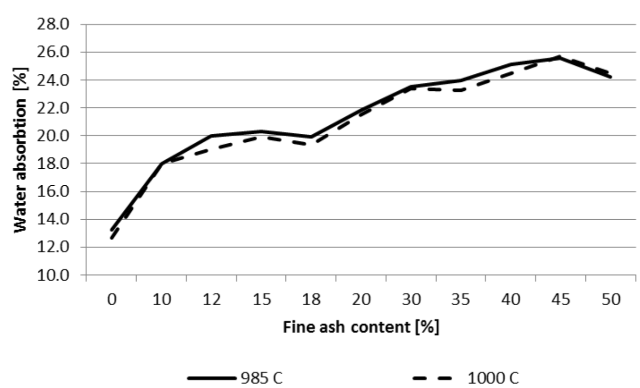


Fig. 3. Water adsorbtion capacity

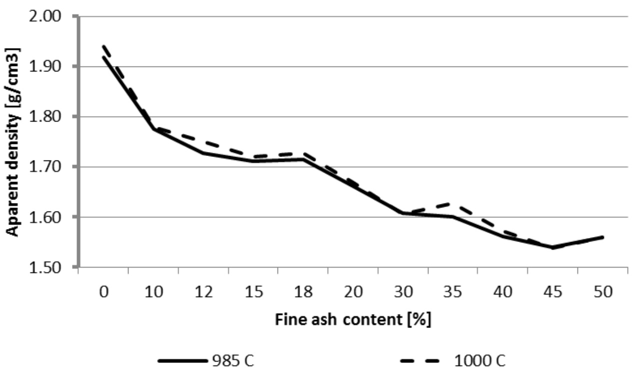


Fig. 4. Aparent density

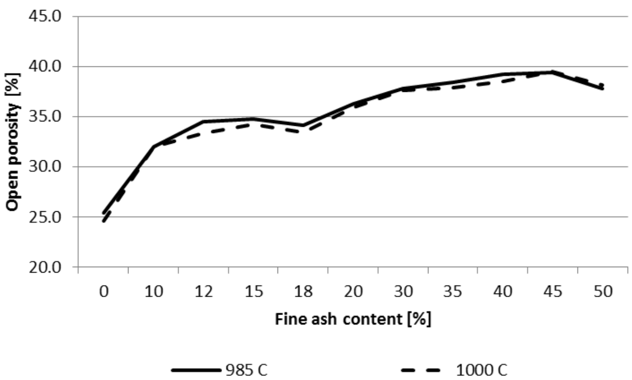


Fig. 5. Open porosity

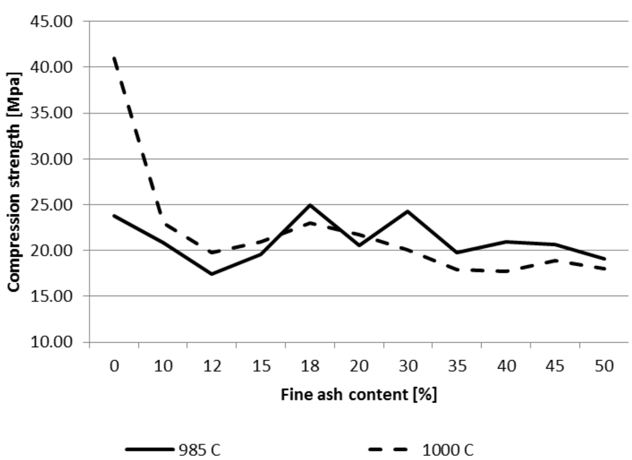


Fig. 6. Compression strength

A high content of ash adversely affects the compressive strength of the products, and thus is necessary to determine optimal content of ash, depending on the final destination of the manufactured products, and the allowable limits of the compression strength for each case.

Fine ash from the power plant can be used as granular aggregate in lightweight concrete compositions, along with other materials from the same class of density (power plant slag, expanded perlite). If hydraulic bonding is ensured by using a refractory binder as aluminum-calcium cement, these new types of concrete can be a useful embodiment of the implementation of thermal insulating refractory linings, on walls characterized by maximum temperatures up to 1100 0C, as notes in the table summarizing the characteristics determined on two experimental variants tested in the project (table 3).

Table 3. The main characteristics of the new types of concrete

Parameter	Type of concrete		
	Temperature	Bh1	Bh2
Density, g/cm^3	110 ^{0}C	1.31	1.01
	1100 ^{0}C	1.25	0.93
Apparent density, g/cm^3	110 ^{0}C	1.35	1.02
	1100 ^{0}C	1.28	0.96
Water adsorbtion, %	110 ^{0}C	32.0	46.8
	1100 ^{0}C	41.0	68.9
Open porosity, %	110 ^{0}C	43.4	47.9
	1100 ^{0}C	52.5	65.9
Open porosity, %	110 ^{0}C	11.97	6.07
	1100 ^{0}C	3.89	3.07
Linear variation, %	1100 ^{0}C	-1.84	-1.67

IV. Conclusions

The separation of carbonaceous solid residue from coal ash can be achieved by physical methods based on size distribution and density differences. By such methods, the properties of the residual carbon correspond to characteristics of semi-coked lignite (no oxide components).

The fine fraction from coal ash, obtained after the organic component separation, can be considered as an alternative source of lightweight granular aggregate (bulk density from 0.7 to 0.9 g/cm3) and can be successfully used to achieve building materials of 1.0 - 1.2 g/cm3 density class.

Due to the thermal stability conferred by way of providing (coal combustion residue discharged at temperatures above 1100°C) and when is used in combination with suitable hydraulic binders, coal ash provides the possibility of obtaining heat resistant lightweight concrete of the same density. In such applications, ash can substitute natural lightweight granular aggregates, such as calcined diatomite.

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