COMPARISON BETWEEN THE PROPERTIES OF BUILDING MATERIALS MANUFACTURED FROM BOTTOM ASH AND FLY ASH PART I. MATERIALS AND PROCEDURES

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Abstract. Bottom ash resulting from combustion of low-quality lignite in Romanian coal-fired power plants contains significant amounts of unburned carbon. This large value is caused by many factors, such as the high humidity value of the raw coal delivered to the plant, advanced wear of the coal mills and large variability of the coal quality. As the unburned carbon reduces significantly the economic efficiency of the power generation, solutions to improve the process were investigated.
Within the CHARPHITE project we propose a recycling process of coal ash for obtaining a carbon concentrate that can be used as raw material for graphitization procedure. Various secondary waste materials result from separation and concentration phases of the recycling process.
We point out the possibilities to use the by-products with very low carbon content as substitutes for natural aggregates in ceramic bonded construction materials. We tested two kind of coal ash: bottom ash collected from a Romanian power plant and fly ash collected from a Portuguese power plant.
In the first part of the paper we present the coal ash characteristics and the methods used to determine them.

Keywords: coal combustion products, building materials

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1. INTRODUCTION

Coal-fired power plants cover worldwide a significant percentage of the electricity demand, with variations dependent on local availability, presence of other primary energy resources and national policies in the respect of energy. With environmental regulations becoming increasingly restrictive and cleaner production concept strengthening its position as an industrial standard, coal processing technologies, from combustion to final waste management, must comply with higher standards regarding utilization efficiency and environmental impact.

Coal utilization technologies cause environmental impact through two main ways:

- extraction and primary processing and
- combustion and management of the final waste material.

Waste material is perhaps the most problematic and it has carefully been considered. Flue gas cleaning technologies reached performances that comply even with the most restrictive environment regulations. Ash resulting from coal combustion, on the other side, is still a problem only partially solved.

Pulverized burning of coal produces two types of ash, both of which present a high risk of pollution if they are discharged into the ash and slag deposits:

- **Fly ash**. Fly ash accounts for more than half of the coal combustion products (CCP). The fly ash particles are light and are driven by the flue gas and discharged from the boiler. The electrostatic precipitators capture over 99 % of the ash, attracting it with opposite electrical charges. The fly ash is recyclable. The particles are fine and solidify, especially when mixed with water, Due to the uniform particle size and the pozzolan properties, the fly ash is widely used as a mixture in cement, as a filling layer or for the manufacture of building materials.
- **Bottom ash**. Bottom ash is a heavier component of coal ash, comprising nearly 10 percent of CCP. Due to the larger dimensions and weight, the flue gas cannot drive the ash and it falls on the rear grill from the boiler base. The variation in very large limits of the particle size and of the chemical composition, as well as relative high carbon content, greatly limits recycling possibilities without preliminary processing. A small part of the bottom ash is used in concrete or in some building materials as a substitute for natural aggregates (sand, gravel and crushed stone) or in asphalt mixtures.

According to the American Coal Ash Association (ACAA), recycling rate of fly ash in concrete and concrete products has been reported to be 47%, while for bottom ash this rate has been reported as only 5.28% of the total recycling amount [1].

In Romania there are 108 ash deposits occupying an area of nearly 2800 ha. The volume of ash stored over the years is huge, on the order of thousands of millions of cubic meters. Even though many of these deposits are no longer used, they adversely affect the environment by [1 .. 5]:

- 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.

2. THE CHARPHITE PROJECT

The main objective of the CHARPHITE project [6] was the separation of the unburned carbon (char) from the ash and its concentration to over 50% without the use of any substances that could contaminate the final product. Due to this condition, we used only three methods for char concentration [7]: dimensional sorting (sieving), magnetic separation and gravimetric separation (floating in water). Laboratory experiments shown that each of these concentration methods has their own efficiency limits and in order to obtain a higher purity of the residual carbon we have developed combinations of the above concentration methods.

In total, we studied 12 procedures for preconcentration of char and we compared them using four parameters:

- final fixed carbon content;
- overall mass separation efficiency;
- efficiency of char concentration;
- efficiency of char recovery.

Through the procedures used, the UCB team obtained the increase of the fixed carbon content from 13.89% to 63.60% and the decrease of the mineral mass in the tested samples from 57.57% to about 17.39%. The samples were carbonized at high temperature, the volatile matter being removed. The weight of the char increased to 78%.

The results obtained were validated by the specialized laboratories from two partners: University of Johannesburg and University of Porto.

Being a "cascade" procedure, the separated ash fractions with a lower fixed carbon content and not used for preconcentration were considered for subsequent use as by-products. The main differences between the separate fractions are the average particle size and the char content. They can be classified according to their carbon content, as follows:

- fractions with medium carbon content. They can be used for briquetting or reinsertion;
- fractions with low carbon content. They can be used for pore formation (by combustion) in the case of light construction materials;
- fractions with very low carbon content. They can be used as substitutes for natural aggregates in hydraulic or ceramic bonded construction materials.

3. MATERIALS AND METHODS

Two classes of methods were employed in order to establish possible recycling technologies of coal ash:

- Pressing followed by hot binding
- Compaction by means of vibrated casting of the mixtures based on hydraulic binder

For manufacturing the ceramic bonded samples, we used the following materials:

A. Bottom ash-clay samples

- Bottom ash less than 2 mm in size, fraction that has less content of organic materials, as determinations made in stage II shown.
- Ceramic binder, represented by the coarse gray clay recovered from the excavation materials resulted in the lignite exploitation works in the open pit Roșia de Jiu – Rovinari

We manufactured 240 samples, using eight clay-ash mixing options, with ash concentrations between 0 and 51% - table 1.

Table 1. Characteristics of bottom ash – clay mixtures.

Sample	Component [%]		Water [%]
	Clay	Bottom ash < 2 mm	
BA1	100	0	14.2
BA2	96	4	13.1
BA3	86	14	17.0
BA4	76	24	15.9
BA5	66	34	18.2

BA6	61	39	16.1
BA7	56	44	16.7
BA8	49	51	18.1

B. Fly ash-clay samples

The following materials were used to make ceramic bonded samples:

- Four types of fly ash from the Pego thermoelectric power station, Portugal, respectively:
  - Type A - fly ash, taken from the electrostatic precipitator
  - Type B - fly ash with low-carbon content
  - Type C - fly ash with low carbon and iron content
  - Type D - fly ash with low-carbon and very low-iron content

The B-type ash results after separation and elimination of the unburned carbon from A-type ash by dry sieving and flotation separation.

The C-type ash results after separation and elimination of the magnetic particles from B-type ash using a low magnetic field using ferrite magnets

The D-type ash results after separation and elimination of the magnetic particles from C-type ash using a high magnetic field using Neodymium magnets.

- Ceramic binder, represented by the coarse gray clay recovered from the excavation materials resulted from the lignite mining works at Roşia de Jiu - Rovinari

We manufactured 170 samples, using four clay-ash mixing options for each type of fly ash, with ash concentrations between 0 and 25%.

Table 2. Characteristics of fly ash – clay mixtures.

Sample	Component [%]		Ash type
	Clay	Fly ash	
FA 0	100	-	-
FA A1	95	5	A
FA A2	90	10	A
FA A3	85	15	A
FA A4	75	25	A
FA B1	95	5	B
FA B2	90	10	B
FA B3	85	15	B
FA B4	75	25	B
FA C1	95	5	C
FA C2	90	10	C
FA C3	85	15	C
FA C4	75	25	C
FA D1	95	5	D
FA D2	90	10	D
FA D3	85	15	D
FA D4	75	25	D

The ash samples were tested in laboratory to determine the moisture concentration, bulk density and granulometry.

The moisture content was determined by drying the sample in an electric oven (150 liters capacity) at a temperature of 110 ^{o}C ± 2 ^{o}C by holding the maximum temperature for 10 hours – fig.1.

Fig.1. Drying process of the ash samples

Bulk densities (freely settled and tapped) and granulometry were determined after samples drying. The bulk density was determined following gravimetric method of

STAS 1913/3-76 by weighting a known volume of bottom ash sample and using a gradated cylinder and an analytical balance – fig.2.

Fig. 2. Bulk density determination

To determine the bottom ash samples granulometry on a mass basis, a mechanical sieving trial was conducted using a set of standard R20 sieves (fig. 3) with the following nominal sieve opening in mm: 4, 2; 1, 0.5, 0.25, 0.125, 0.09, and 0.063.

Fig. 3. Granulometry determination

We homogenized the mixtures 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. Ten test samples were prepared from each mixture.

Fig.4. Manufacturing of ash samples

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 ^{o}C ± 2 ^{o}C, the maximum temperature being maintained for 10 hours.

Fig.5. Drying the ash samples

After drying, the samples were fired in an electrical furnace by applying a growing gradient of temperature of 3 ^{o}C /min, the maximum temperature being maintained for 3 hours (Fig. 1). thus:

- The bottom ash-clay samples at temperatures of 970 ^{o}C, 1000 ^{o}C and 1030 ^{o}C.

- The bottom ash-clay samples at temperature of 1000 ^{o}C,

Fig.6. Burning the ash samples

4. CONCLUSION

Coal ash recycling is an imperative due to the environmental risk of this waste material. The research teams involved in CHARPHITE project developed specific process flows for obtaining synthetic graphite. The secondary waste materials resulting from various phases are further processed and sorted. The secondary waste fractions with relatively uniform properties are finally obtained and they were used as substitutes for natural aggregates in ceramic bonded construction materials.

References

[1]. Cristinel Racoceanu, Study on influence of noise dispersion on air quality in the area of rovinari thermal power plant, Annals of the „Constantin Brâncuşi", University of Târgu-Jiu, Engineering Series, no.4 /2018, pag 13-16, ISSN1842-4856.

[2]. Cucu, Mihai Gabriel, et al. "Polymorphisms in autophagy genes and active pulmonary tuberculosis susceptibility in Romania." *Revista Romana de Medicina de Laborator* 25.1 (2017): 47-53.

[3]. Cristinel Racoceanu, Study on the reduction of polluting emissions through combustion biomass in the thermal boilers, Annals of the „Constantin Brâncuşi", University of Târgu-Jiu, Engineering Series, no.4 /2018, pag 17-20, ISSN1842-4856.

[4]. Popescu, Luminita Georgeta, et al. "Environmental impact of ash and slag deposit Ceplea Valey of Energetic Complex Turceni." International Multidisciplinary Scientific Geo Conference: SGEM: Surveying Geology & mining Ecology Management 5 (2012): 345.

[5]. Popescu, Luminita Georgeta, et al. Analysis of heavy metal content to evaluate leaching characteristics of coal ash wastes. International Multidiscipli-nary Scientific Geo Conference: SGEM: Surveying Geology & mining Ecology Management 1 (2013): 33.

[6]. Santos, A., et al., 2017. Project CHARPHITE: presentation and up to date of Porto University results. Jornadas do ICT, 26-27 Junho, Universidade do Minho. Book of abstracts, pag. 38.

[7]. Cruceru, Mihai, et al. Possible uses of coal in circular economy." International Multidisciplinary Scientific Geo Conference: SGEM: Surveying Geology & mining Ecology Management 18 (2018): 113-120.

[8]. Valentim, Bruno, et al. "Undifferentiated inorganics in coal fly ash and bottom ash: Calcispheres, magnesiacalcispheres, and magnesiaspheres." *Minerals* 8.4 (2018): 140.

[9]. Santos, A., et al., 2017. Project CHARPHITE: presentation and up to date of Porto University results. Jornadas do ICT, 26-27 Junho, Universidade do Minho. Book of abstracts, pag. 38.

[10]. Badenhorst, C., Wagner, NJ., 2017. Char extracted from coal ash as a replacement for natural graphite – Charphite. FFF Conference on Sustainable Development of South

Africa's Energy Sources, 29-30 Nov 2017, Johannesburg

[11]. Popescu Cristinel, Racoceanu Cristinel - Aspects regarding the efficiency achievedby replacing the auxiliary generator with electrical transformer of 20 / 0.6 kV at the synchronous generators of 330 MW. International Multidisciplinary Scientific Geo Conference SGEM 2016, Book1 Vol. 2, 79-84 pp.

[12]. Popescu Cristinel, - Aspects regarding the inspecting and monitoring of insulation at medium voltage electrical cables used in power didtribution systems, Annals of the „Constantin Brâncuși University of Târgu Jiu, Engineering Series, No. 1/2018,pp.62-66.