Bottom ash as granular aggregate to manufacturing of lightweight heat resistant concretes

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***Abstract*—** Heavy ash from thermal power plants (bottom ash) can be considered as an alternative source of lightweight granular aggregate (bulk density from 0.7 to 0.9 g/cm^3) and successfully used to achieve building elements of 1.0 - 1.2 g/cm^3 density class. In addition, due to the thermal stability conferred by way of providing (coal combustion residue discharged at temperatures above 1100°C) and when used in combination with suitable hydraulic binders, bottom ash provides the possibility of obtaining heat resistant lightweight concrete of the same density class and characterized by the maximum service temperature up to 1150°C. In such applications, ash can substitute natural lightweight granular aggregates, such as calcined diatomite.

***Keywords*—** bottom ash, heat resistant concrete, lightweight aggregate, lightweight concrete.

I. Introduction

Ash resulted from coal burning into steam generator boilers of large power plants, are industrial waste which rise major problems for the environment, both in terms of large quantities currently generated, and accumulated in time in specific deposits. If for the fly ash, taken in the flue gas and trapped in electrostatic precipitators is possible in 100% the recovery in cement for construction manufacturing flows, for heavy ash (slag, bottom ash) virtually no current use exists, the amount valued being insignificant compared to the products. Consequently, this type of industrial waste continues to be accumulated in large warehouses, capable of altering the natural landscape of the area including large power plants (figure 1).

Figure 1. Ceplea Valley ash dump – Branch Electrocentrale Turceni

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ROMANIA The thermal power plant ash is a material of interest to researchers in the field of building materials, literature providing multiple examples of this. The bottom ash is used in the production of prefabricated building with about 1 kg/dm^3 density [1], autoclaved aerated concretes, masses of sprayed concrete compaction for construction and repair [2]. Also, on the basis of similarity of composition of limestone, clays (quartz, feldspar, illite, smectite, calcite), the ash is used as an additive in mixtures for directly burned brick [3,4,5] or to obtain special building materials glass-ceramic type, either by direct melting at approx. 1500^{0}C [6], or in admixture with other oxide components (lime, dolomite, rutile) [7,8,9,10].

Studied the possibility of using bottom ash in construction materials manufacturing, both as such, and in combination with two other important industrial waste: oil drill cuttings and steelmaking slags. The main source of waste was selected ash discharged from coal combustion power plants of Oltenia Energy Complex - Branch Turceni transported by hidromixture process (report ash/water 1:10) and stored in Ceplea Valley deposit - Compartment No . 2. Deposit surface is of approx. 52 hectares, the amount of stored ash being estimated at approx. 20 million tonnes [11].

Assessing the possibilities of bottom ash use as an alternative feedstock for the manufacture of insulating concrete was made under specific physico-chemical characteristics determined by laboratory tests on representative samples taken from the Ceplea Valley deposit. Wishing to meet a classification criteria often overpassed in industrial application practice, lightweight concretes studied we associate the generic name of "heat-resistant" highlighting that (through the properties) they could not be included in refractories (materials that, in Seger test conditions, reach or exceed the limit of 1580^{0}C).

II. Bottom ash characteristics

In terms of chemical and mineralogical composition, bottom ash belongs to quaternary oxide system SiO2 - Al2O3 - CaO - Fe2O3. Basic oxide content varies relatively small: 40-50% SiO2, 15-20% Al2O3, CaO 9-14, 8-9% Fe2O3, and X-ray diffractometer analysis shows the presence of predominant α-quartz, hematite and anorthite (CaO.Al2O3.2SiO2) [12]. Consequently, the industrial waste can be likened to a weak burnt grog obtained from a calco-ferrite clay. In physical terms, the ash transported and stored by hidromixture process can be considered as a slightly granular aggregate (dry bulk density 0.7-0.9 g/cm3) with fine particle size distribution. From this point of view there is a very good constancy of the particle size composition, as it can be seen in the graph of Figure 2, in which are shown the results obtained on four ash samples taken from a lot of approx. 18 tons, and in which is observed that practically the four graphs overlap.

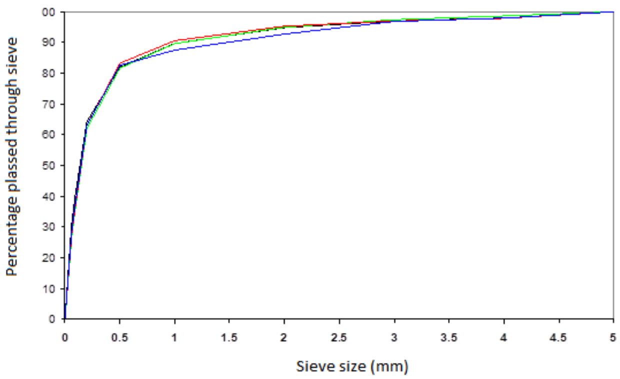

Figure 2. Grain size distribution for 4 ash samples

Ash is the solid residue resulting from the combustion of energy coals, a process by which oxide mineral compounds from coal (sterile) undergone physical-chemical changes specific for heat treatment at high temperature (above 1100°C), and that are likely to provide thermal stability at least up to the temperature characteristic of the burner combustion system. The proof is mineralogical composition, that the ash does not reveal the presence of free CaO, alone or in hydrated form.

The thermal stability of the bottom ash has been carried out in laboratory specific tests [12], determined by means of high-temperature microscope, that follows the changes undergone by the test specimen geometry cube of 4x4x4 mm ash with increasing temperature. Images representative of this transformation, taken during a test are shown in Figure 3.

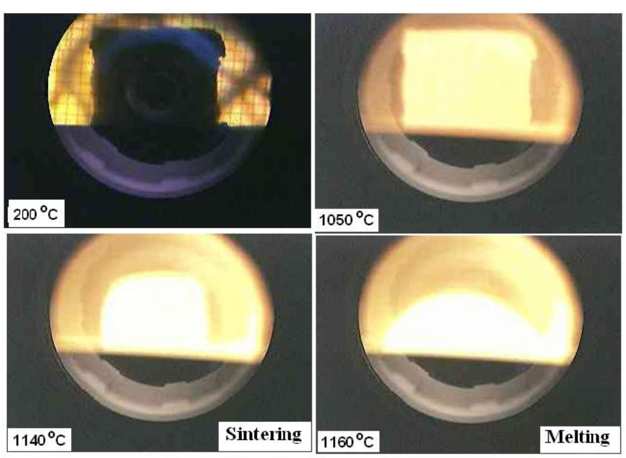

Figure 3. Thermal microscopy for bottom ash sample

III. Experimental

Based on the physical-chemical characteristics of bottom ash, mentioned above, within Project LIFE 10 ENV/RO/729 was verified experimentally the possibility of using this type of industrial waste as lightweight granular aggregate to manufacture lightweight heat-resistant concretes. To ensure certainty of the conclusions in this regard, were tested simple concrete mixtures, in which the bottom ash was uniquely granular aggregate. As a hydraulic binder in concrete, have been used two types of concrete produced and currently delivered to the market by LAFARGE company:

- Portland cement mark CEM I 52,5 R, a special fast curing cement at which the main mineralogical compound of clinker represents tricalcium silicate (C3S), feature that makes it suitable for use in concrete compositions thermally stressed at work service;

- aluminous cement Fondu Lafarge containing 40-42% Al2O3 and typical calcium monoaluminate (CA) as the main mineralogical compound of clinker, alongside of heptaaluminate (C12A7) and brownmillerit (C4AF). Fondu Lafarge is a typical refractory cement for use in the manufacture of concrete with maximum service temperature up to 1450^{0}C.

Main physical characteristics of utilized cements are presented in table 1.

Table 1

Physical characteristics of cements (according to EN 196)

Cement type	Ratio water/ cement	Curing time		Compression strength (MPa)		
		Start	End	At 1 day	At 3 days	At 7 days
CEM I 52,5R	0,5	2h5'	7h25'	21,5	41,6	61,3
Fondu Lafarge	0,4	4h30'	12h30'	36,8	72,5	84,0

In both variants, for obtaining concrete blends have been applied the same gravimetric dossing charge of the components:

- thermal power plant ash 70% (equivalent dry ash)
- hydraulic binder (cement) 30%

Fresh concrete blends were made with the addition of potable water, until the normal consistency adequate for putting into practice by casting vibrator.

Fresh concrete was compacted immediately after mixing, in standard metal patterns for specimens with dimensions of 100x100x100 mm and 160x40x40 mm. Compaction was carried out by shaking for 3 minutes, using standard lab vibrating table (frequency 50 Hz, amplitude 0.5 mm).

Demoulding of specimens was performed after 24 hours from the time of manufacture. After demoulding, the specimens were kept at 20^{0}C, in conditions of humidity storage, up to the time of the heat treatment.

At 72 hours after making, the samples were subjected to drying in laboratory oven at 105^{0}C, with soaking time of 8 hours at maximum temperature.

Burning dry specimens was performed in laboratory electric furnace with temperature gradient of 5^0C/minute for 4 hours in maximum levels of 600^0C, 800^0C, 900^0C and 1000^0C for both compositional variants, respectively 1100^0C and 1150^0C for concrete (Figure 3).

Figure 3. Pieces of burned lightweight concrete.

After cooling, the samples were subjected to laboratory tests, according to the conditions set out in EN 1402 (unshaped refractories). Laboratory test results are shown in Table 2.

Table 2

Results of laboratory physical-mechanical trials

Characteristic		Value	
		BIC_P	BIC_T
Water, %		32.4	30.7
Apparent density, g/cm^3	600 ^{0}C	1.22	1.22
	800 ^{0}C	1.16	1.22
	900 ^{0}C	1.15	1.21
	1000 ^{0}C	1.42	1.18
	1100 ^{0}C	-	1.22
	1150 ^{0}C	-	1.21
Opened porosity, %	600 ^{0}C	47.43	52.01
	800 ^{0}C	53.78	51.08
	900 ^{0}C	56.06	52.09
	1000 ^{0}C	50.68	54.98
	1100 ^{0}C	-	51.96
	1150 ^{0}C	-	47.48
Compression strength, MPa	110 ^{0}C	6.26	6.17
	600 ^{0}C	5.28	5.63
	800 ^{0}C	3.87	3.84
	900 ^{0}C	3.14	3.09
	1000 ^{0}C	1.14	3.63
	1100 ^{0}C	-	3.83
	1150 ^{0}C	-	5.08
Linear dimensional variation after firing and cooling, %	600 ^{0}C	-0.62	-0.61
	800 ^{0}C	-1.19	-0.74
	900 ^{0}C	-1.48	-0.97
	1000 ^{0}C	-3.22	-1.09
	1100 ^{0}C	-	-1.08
	1150 ^{0}C	-	-1.45

IV. Discussion and Conclusion

In designing and implementing the industrial heat insulating linings, monolithic materials (insulating concrete) offer of indigenous production is dependent on the provisions of STAS 11485-91, which for field density 1.0 – 1.2 g/cm3 and maximum temperature 1400^0C recommended only use of three types of products:

- Lightweight concrete BI 17A10 (fused alumina binder) and BI 33A10 (bonded super aluminous sintered) in which aggregate granular composition is calcined diatomite and maximum service temperature of 1150^0C;
- Lightweight concrete BI 60A11 (super aluminous sintered and bonded maximum service temperature of 1400^0C), which is used to manufacture synthetic lightweight granular aggregate of Al_2O_3 content of 45%.

There are also, guaranteed by national technical norms, concrete BIZ version 1.0 based on granulated blast furnace slag, with maximum service temperature of 1050^0C, provided in the conditions of hydraulic binder use of refractory cements with low content of Fe_2O_3 (super aluminous cements).

Manufacture of insulating concrete mentioned is limited, at present, to the following conditions:

- calcined diatomite is not provided at the request level. Contribute to this both unprofitability career extraction as well as major environmental problems involved by mineral rock calcined (massive emissions of SO_2);
- granulated blast furnace slag is either unavailable (higher recovery in addition to the grinding Portland cement), or nonexistent (drastic reduction in the production of iron and steel industry in Romania);
- use as granular aggregate of synthetic lightweight chamotte and as binder of sintered super aluminous cements, determines higher manufacturing costs and delivery, in which foreign producers offers become more favorable.

In these conditions, bottom ash enables the production of thermal-insulating concretes having a maximum service temperature of 1150^0C, in variant of minimum cost of lightweight granular aggregate. In addition, the ash provides the possibility to use Portland type hydraulic binders in the production of concrete, in that of being involved with the active oxide components (α-SiO2, 2CaO.SiO2, Fe2O3), known to have an effect of stabilizing the binder properties at high temperatures.

Although insulating concrete is not usually associated the requirement of high mechanical resistance (they never have the lift role in the construction of thermal units linings), characteristic values of this order, correlated with the density, porosity and dimensional change, after firing and cooling, are determinant to define the maximum service temperature.

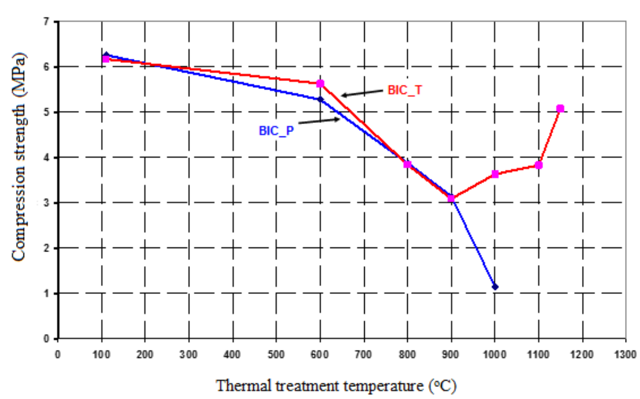

Figure 4. Compression strength variation on firing temperature

The variation of compression strength of concretes studied is represented in Figure 4 based on the results presented in Table 2. Following the parameters given in Table 2 and graphs of Figure 4, it is observed that in case of use of Portland cement as a hydraulic binder, firing at temperatures above 900 °C cause a significant drop in the mechanical strength, while varying the density, porosity and linear shrinkage which suggest the formation of a liquid phase of more than 10%, that damage resistance structure after cooling. The results obtained are also important in that they confirm data of the literature regarding the minimum values of concrete compressive strength of the alumina based refractory cements record in the temperature range of 600-900^{0}C, respectively the possibility to use up to the maximum service temperatures of the cements having a delivery cost much lower.

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