

Petrographic Assessing of Combustion Waste Products Quality Resulting from Berbești Lignite Burning in Govora Power Plant

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The paper aims to establish the relationship between Berbesti lignite composition and of the combustion waste products (CWP) formed during combustion in Govora power plant. Besides physico-chemical methods, the petrographic research confirms the CWP quality dependence on feed lignite characteristics (rank and maceral composition) and their behaviour during thermal treatment, the optical texture providing information on the organic/inorganic ratio. The composition of combustion residues, evaluated microscopically, offer a better knowledge of combustion process and CWP quality (wastes having an increased environmental impact), but the choice of the best ways of recycling, including for new construction applications.

Keywords: lignite, thermal treatment, recycling combustion waste products, optical microscopy, construction materials.

A variety of combustion residues are generated during burning coals in the power plants which exhibit complex composition depending mostly on coal type and thermal treatment. Coal combustion waste products (CWP), fly-ash, bottom ash and slag are, as generated amounts, the major wastes which are produced in the world, including Romania [1].

Coal bearing deposits of Oltenia Mining Basin belong to upper Pliocene represented by Dacian and Romanian floors and basal part of the Quaternary (lower Pleistocene). The perimeters of the working opencast pits spread over three counties are: 10% Mehedinți (Mehedinți coalfield), 82% Gorj (Motru, Jilț, Rovinari and Albeni Roșia de Amaradia coalfields) and 8% Vâlcea (Berbești coalfield) are shown in figure 1 [2].

The geological structure of the deposit, exploitation type, nature of sterile intercalations of typically Pliocene origin and characteristics are well known from previous

researches [3]. They were focused on the geological setting of Oltenia Coal Deposits, as well as on lignite main component (xylite), its size characteristics and petrographical structural composition [4]. It is well known that in the grinding process for coal dust preparation, xylite's elasticity cause the premature damage of the mills and increased energy consumption. After burning in the combustion chamber, xylite is found almost unchanged (as weakly pyrogenated particles) in the bottom ash and partially burned in fly-ash [3-6].

Currently, large quantities of ash are used for landfilling which cause negative environmental impacts such as air and soil pollution, and leaching of potentially toxic substances into soils and groundwater. The best way to solve the disposal problem of ash is to decrease the quantity for disposal with utilization of ash in the industry [7, 8]. The increasing demand of energy production leads to the world production of about 600 million tons of fly-ashes, and this value will increase in the near future [9].

In Romania, the impact due to lignite burning in thermal power plants represents a major environmental and economic concern. Waste disposal by landfill represents in our country the most important way to eliminate industrial waste, 75% of which being stored every year, with considerable costs for storage places construction. Govora coal power plant is producing electricity and thermal energy using as main fuel Berbesti lignite (2 mil t/year), the surface of ash deposits totaling 60 ha. Within Govora power plant the residues from the combustion of lignite are stored or reused, thus: (i) Bottom ash and slag are stored; (ii) Ash - eliminated from number two gas funnels route is hydraulically extracted or dry, as three types: (1) Ash before regenerative combustion air pre-heater; (2) Ash-cement - mixture of fly-ash collected in the electrofilters; (3) Ash-concrete - certified according to the concrete standard [10].

The main constituents of ash are Al_2O_3 , Fe_2O_3 , CaO , MgO and in smaller quantities Na_2O and K_2O . However, the diverse chemical, mineralogical and morphological properties of ash offer an opportunity to process it and



Fig. 1. Location of lignite exploitation perimeters of Oltenia Mining Basin in South West Romania [2].

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recover various fractions with particular attributes. A variety of fly-ash has been converted into useful ceramics and glass-ceramics (GCs) used as architectural components in buildings, by several research groups [7, 11, and 12].

Information on chemical and petrographical characteristics of Romanian coals and CWP [13-15], including Oltenia's lignites were published, including the use for ceramic composites manufacturing [16-18]. Information provided by characterizing of fly-ash, about un-burned carbon content and inorganic fraction, prove to be of great importance in describing associations between different components or individual particles in order to predict its behaviour. For commercial use (such as constructions) fly-ash quality with low carbon content is requested. Petrographic composition analysis provides important details about the texture of coal particles or partially burned/degassed (char), of porosity and wall thickness of cenospheres components, aspects that can be related to the origin and their behaviour during combustion process [19]. Investigation of the use of bottom ash as an alternative source of lightweight granular aggregate [20], high temperature behaviour and sintering mechanism of fly ash based concretes [21] including some other authors reports on ash utilisation in construction have also published [22-24]. The use of CWP in new construction application represents a real approach that involves a more complex and wider investigation, including by petrographic research.

The key objectives of this paper, which is a part of an extended study, is to reveal the decisive role of petrographic methods in assessing the quality of lignite burning residues and by investigating the organic and mineral matter behavior during combustion, but also with regard to their possible use as precursors for new construction application.

Experimental part

Materials and methods

Two individual coal samples (aprox. 2 kg. each) were selected from the conveyor belts transporting the crushed lignite from open storage deposit (grain size of max. 30 mm), to coal mills and then to coal boiler (CA1, CA4). Three individual ash samples (aprox. 2 kg each) were taken: fly-ash - from electrofilters (CE1), bottom ash - from hydraulic mixture (CE2) and slag - from open deposit (CE3). The equipment included: manual mortar, Retsch AS200 sieves shaker with different sizes of metal sieves with square mesh, Sartorius analytical balance to ensure accuracy in weighing 0.0002 g, heating laboratory oven with a precision of 1°C and electric oven (1000°C) with an

accuracy of $\pm 20^\circ\text{C}$. For elemental analysis was used an elemental analyzer type FLASH - EA, 1112 Series.

For the petrographic analysis, lignite samples were ground to < 1mm size and embedded in epoxy resin. Five mounts in resin were prepared (two coals and three of combustion residues) with a section close to $2 \times 2\text{cm}$ and vertical surface was polished. The particulate blocks were polished using finer wet carborundum papers; final polishing was done using colloidal suspension of Al_2O_3 or diamante powder of $3.00\mu\text{m}$ and $< 1.00\mu\text{m}$.

Lignite maceral analysis and ash particulate population identification were evaluated using the optical microscope IOR MC1 and a point counter of Eltior type. The methods of preparing coal samples and determining structural composition followed ISO 7404-2 and -5 (1994) respectively [25, 26].

For determination of average huminite reflectance have been considered minimum 50 points for each sample (according ISO 7404/5-1994). The reflection capacity has been carried out according to the low rank coals maceral classification system of the International Committee of Coal and Organic Petrology (ICCP), on ulminite B (similar to vitrinite in bituminous coals). Ulminite B is the maceral which belongs to huminite group, subgroup telohuminite, and its reflectance being dependent of rank [27].

The equipment used was a binocular optical microscope Olympus BX51M with a transmission images camera model CCD-1300QB, reflected light (RL), oil immersion and 500x magnification. A synthetic sapphire standard of known reflectance was used.

Results and discussions

For lignite samples, to establish the limit variation of the basic parameters physico-chemical characteristics (ash, volatile, fixed carbon) and elemental analysis were carried out, as in table 1. For ash average samples general physico-chemical characterization was focused to establish the limits variation of the basic parameters, shown in table 2, and dimensional distribution of particles as appears in figure 2.

In table 3 are shown the results of reflectance measurements for Berbesti lignite samples and their repartition on half steps of identified huminite B (bands and grains of 6-10 μm). The average reflectance, shown in Figures 3 and 4, can be rounded at two decimals, the maximum error being in the range of $\pm 1 \times 10^{-2}$. It was found that huminite reflectance corresponds to low rank coals, respectively of the range of 0.2-0.3%. Coalification process

No.	Sample	Proximate analysis			Ultimate analysis				
		A ^{anh}	V ^{anh}	Fixed C	C	H	N	S	O
1.	CA1	41.49	35.92	22.59	41.71	3.93	0.97	0.97	52.42
2.	CA4	38.21	37.25	24.54	43.22	2.45	0.60	1.09	52.64

Table 1
PROXIMATE AND ULTIMATE
ANALYSIS OF LIGNITE
SAMPLES, % WT.

No.	Characteristics	Sample		
		CE1	CE2	CE3
1.	Ash, A ^{anh} , %	99.39	99.63	98.36
2.	Volatiles, V ^{anh} , %	1.15	0.59	1.34

Table 2
PHYSICO-CHEMICAL CHARACTERISTICS OF
THE AVERAGE ASH SAMPLES, % WT.

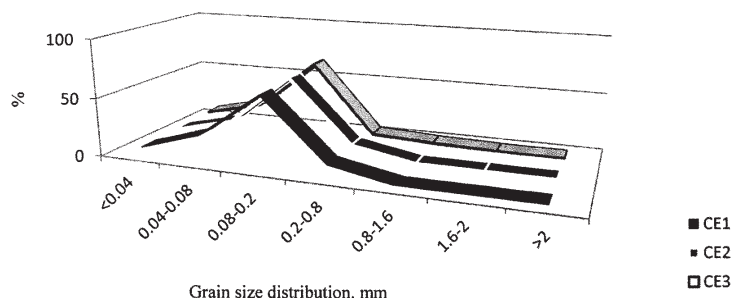


Fig. 2. Grain size distribution of the CWP samples, %

Sample	Open pit mine	Distribution on rank half steps, %				RmH, %
		0.16-0.20	0.21-0.25	0.26-0.30	0.31-0.35	
1	Berbești	2	66	32	-	0.2416
2		10	68	22	-	0.2384

Table 3
AVERAGE HUMINITE REFLECTANCE
OF LIGNITE SAMPLES

COMPONENTS		REPORTED AT	
Maceral group	Maceral subgroups and macerals	Total carbonaceous material	Organic material
H U M I N I T E	Textinite	27.1	36.9
	Structured wooden material	27.1	36.9
	Ulminite	17.8	24.2
	TEXTOHUMINITE	44.9	61.1
	Attrinite	2.8	3.8
	Densinite	-	-
	DETROHUMINITE	2.8	3.8
	Corpohuminite	7.0	9.1
	Porous gelinite	15.1 (13.8)	20.5 (18.8)
	GELOHUMINITE	22.1	30.1
	LIPTINITE	3.1	4.7
	INERTINITE	0.6	0.8
TOTAL ORGANIC MATTER (CARBOMINERITE)		73.5 (20.0)	100.0
	Clay minerals	2.9	
	Ferrous minerals	3.6	
TOTAL MINERAL MATTER		26.5	

Table 4
QUALITATIVE AVERAGE MACERAL
COMPOSITION OF COAL SAMPLES,
% VOL.

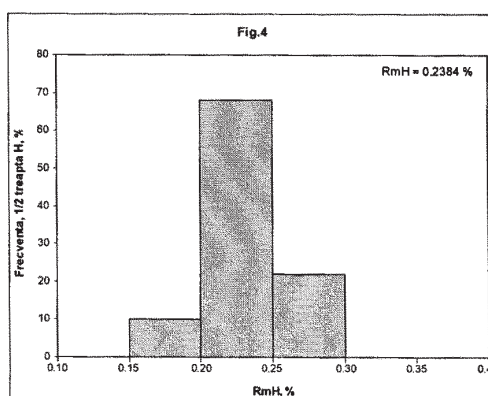
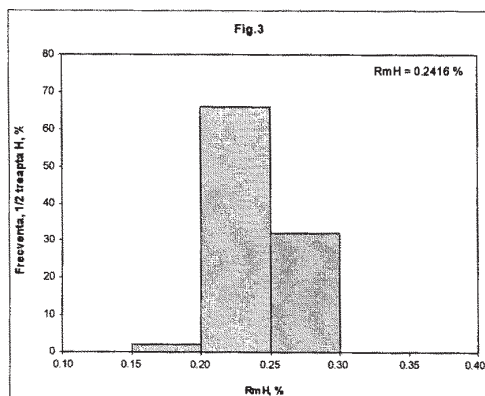


Fig. 3, 4. Lignite samples reflectograms

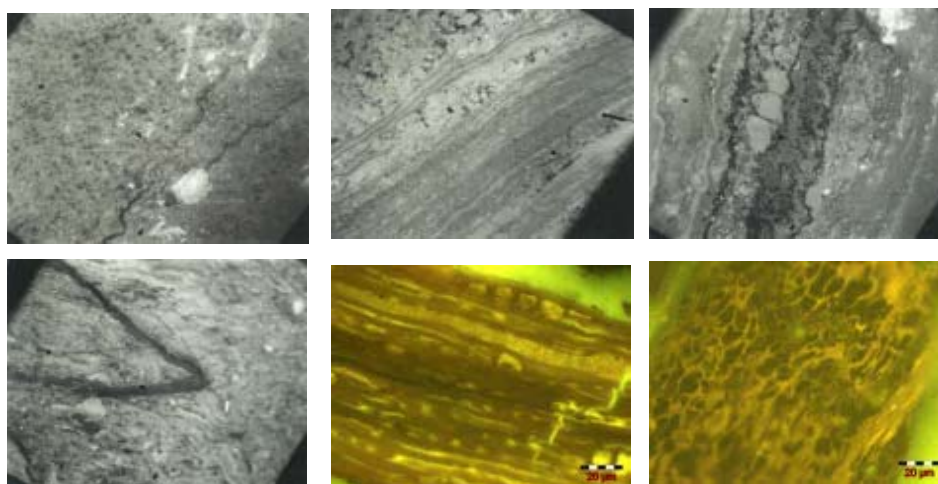


Fig. 5 Microstructural aspects of Berbesti coal samples, reflected light (RL), fluorescent light (FL), glycerine immersion, 32X. (a). textinite with specific porous structure, cuticle (black) and small ferrous impregnation (white). (b). ulminite with alternating bands of textinite and porous corpohuminite (left side, up). (c). cuticles (black) including corpohuminite as bands in ulminite. (d) cuticle and liptinite impregnation (center, left side) in huminitic porous matrix. (e). cellular ulminite in bands with liptinitic intercallations, FL (CA1). (f). textinite having cell walls impregnated with liptinite, FL (CA4)

Sample	Coal, % Vol	Structural optical type
CE1	10.2	izotropic
CE2	13.1	izotropic
CE3	11.5	izotropic

Table 5
TOTAL COAL CONTENT IN ASH SAMPLES,
DETERMINED MICROSCOPICALLY,

is a result of the conditions of storage and processing of vegetable material in the pit swamp deposit under the influence of metamorphic phenomena and mineralogical structure of layers intercalations. The huminite reflectance shows that due to the genetics and diagenesis factors, almost identical, the average value of the two samples are almost similar. For this reason, the petrographic composition (maceral analysis) was performed on the

representative average sample made of the two lignite samples.

The petrographic composition shown in table 4, was determined by maceral analysis, using the huminite classification established by the ICCP [27]. The low coalification degree of lignite is represented either by the proportion of total wooden components of about 37%, in particular of those structured (textinite with liptinite filling

Table 6
TOTAL CARBON CONTENT IN DIFFERENT BURNING STAGES (UN-BURNED, PARTIALLY BURNED, BURNED) IN ASH SAMPLES, DETERMINED MICROSCOPICALLY, % VOL.

Sample	Un-burned	Partially burned	Burned
CE1	14	68	18
CE2	11	60	29
CE3	20	55	25

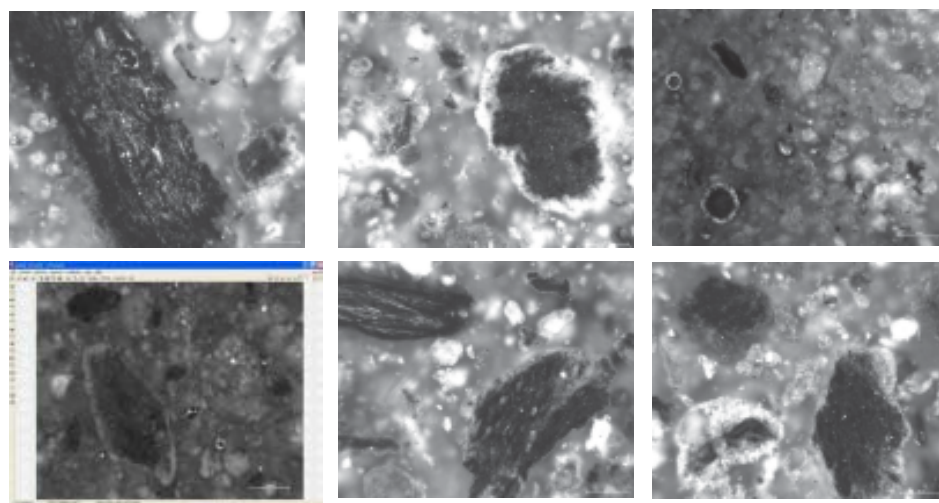


Fig. 6 Photomicrographs of CWP, RL, glycerin immersion, 32X. (a). un-burned coal grain (CE1). (b). coal grain partially burned (CE1). (c). agglomeration of small partially, total and un-burned coal grains in bottom ash (CE2). (d). partially burned and unburned coal grains (CE2). (e). two un-burned coal grains in slag (CE4). (f). coal particles in different burning stages (CE4)

highlighted by the fluorescent light) figure 5a, b, f. Another confirmation of lignite low rank is the presence of ulminite, corpohuminite and gelinite components, as in figure 5b, c, e. Maceral groups of liptinite are present up to 4.7% and are highlighted also in fluorescent light, figure 5e, f. The mineral matter appears as impregnation of the constituents as carbargillite structures and ferrous minerals which frequently and heavily impregnate the textinite.

Present research helps to assess the coal macerals transformation during burning into the power plant boilers. The investigation shows aspects of ash behaviour in close dependence on lignite structural features - rank, petrographic composition and physico-chemical characteristics. This develops specific technological features in terms of thermal process, adsorption chemical reactions, combustion - transformation in gas, ash and slag. As a result of structural and chemical-technical determinations made, was found that the carbonaceous material having ash under 45%, achieve a proper combustion process that allows the formation of a minimum of un-burned or partially burned waste products, favourable to obtain a quality of ash accepted by potential users of new construction applications, tables 5 and 6. The microstructure aspects of charcoal granules (char of fly ash), is illustrated in the micrographs of figure 6.

Conclusions

The results of petrographic analysis, non-destructive, representative and reproducible outlines aspects of physical phenomena that develop during lignite combustion studied, and the factors that determine a particular type, structure and quality of the intermediate or final products (CWP).

Determinations of rank and petrographic composition reveal low degree of coalification and specific maceral composition which can influence the thermal treatment (of combustion). Very low rank of the xylitic coals is compensated by liptinitic impregnation, of bituminous origin, which helps burning and increases the combustion yield, aspect visible in fluorescent light.

In addition to the physico-chemical analysis, structural microscopy reveals that a coal having ash lower than 45% favours the development of a properly combustion process,

allowing the formation of a minimum of un-burned or partially burned particles in the CWP that does not affect the use of ashes in new construction applications.

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References

- PĂNOIU, N., CAZACU, C., MIHĂESCU, L., TOTOLU, C., EPURE, AL., Solid fuels burning installations, Ed. Tehnică, București 1985.
- SCORTĂRIU, O., Geological and geotechnical study of Jilț coal basin and prognosis of the areas subjected to landslides, Doctoral Thesis, Faculty of Mining, University of Petroșani, Romania, 2007.
- PREDEANU, G., PANAITESCU, C., Petrographical evaluation of xylite activated carbon. International Journal of Coal Geology, 71, 2007, p. 542.
- PREDEANU, G., SCORTĂRIU, O., PANAITESCU, C., Qualitative improvement of xylite by mechanical preparation, International Journal of Coal Geology, 2014, <http://dx.doi.org/10.1016/j.coal.2014.08.002>, 11 p.
- BARCA, F., PENU, A., Posibilități de obținere a unui combustibil transportabil la distanță din ligniți din Bazinul Olteniei, Conferința de Chimie și Inginerie Chimică, editia a-IV-a, 1989, București.
- BARCA, F., PANAITESCU, C., PREDEANU, G., The behavior of brown coals with high xylith content on combustion, The Mediterranean Combustion Symposium Proceedings, Cairo, 2002, p. 107.
- BARCA, F., NEAȚU, V., POPA, M., CONSTANTINESCU, I., Rev. Chim. (Bucharest), 26, no.10, 1975, pp. 853.
- CARLSSON, C., L., ADRIANO, D., C., Environmental impacts of coal combustion residues, Journal of Environmental Quality, 22, 1993, p. 227.
- GRAUS, W., WORRELL, E., Trend in efficiency and capacity of fossil power generation in the EU, Energy Policy, 37, 2009, p. 2147.
- SR EN 45—1:2012, Fly-ash for concrete – EN 450-1:2012 – Category A, N.
- BOCACCINI, A., R., KOPF, M., STUNPFE, W., Glass-ceramics from filter dusts from waste incinerator. Ceramic International, 21, 1995, p. 231.
- KARA, A., KURAMA, H., KARA, Y., KURAMA, S., Utilization of coal combustion fly-ash in terracotta bodies, Key Engineering Material, 2004, 264-268, p. 2513.

13. PANAITESCU, C., PREDEANU, G., *Carbopetrografic Atlas*, Ed. Academiei Române, București, 1999, 264 p.
14. MARIN, E., E., Composition and structure of energy coals representative for the carboniferous basins of Romania with regard to their utilization, Doctoral Thesis, Faculty of Industrial Chemistry, University Politehnica Bucharest, Romania, 2003.
15. PANAITESCU, C., PREDEANU, G., MIU, M., Petrographic characteristics of some Romanian high volatile bituminous coals and solid byproducts resulted during their pulverized combustion in a power plant. 60-th Annual Meeting of the International Committee for Coal and Organic Petrology, 25th Annual Meeting of The Society of Organic Petrology, 2008, Oviedo, Spain.
16. PREDEANU, G., VOLCEANOV, E., ABAGIU, T., A., CRUCERU, M., SLĂVESCU, V., RACOCEANU, C., Coal ash characteristics to assess its possible uses. 13th International Multidisciplinary Scientific GeoConference SGEM 2013, June 2013, Albena, Bulgaria Energy and Energy and Clean Technologies Proceedings, p. 309.
17. ABAGIU, T., A., VOLCEANOV, E., PREDEANU, G., ZĂMAN, F., POPESCU, L., G., SLĂVESCU, V., Physical-chemical characteristics of some industrial wastes arguments for their use in the field of building materials manufacturing. 13th International Multidisciplinary Scientific GeoConference SGEM 2013, June 2013, Albena, Bulgaria, Energy and Clean Technologies Proceedings, p. 409.
18. PREDEANU, G., VOLCEANOV, E., ABAGIU, T., A., POPESCU, L., G., Evaluation of ash utilization as a reuse material for the ceramic industry, WSEAS International Conference on Advances in Environment Technologies, Agriculture, Food & Animal Science, Proceedings of the 2nd International Conference on Energy and Environment Technologies and Equipment (EEETE'13), June 2013 Brasov, Romania, Energy, Environmental and Structural Engineering Series 10, edited by V. Marascu-Klein, M. Cruceru, M. Ciontu, p. 224.
19. PREDEANU, G., ABAGIU, T., A., POPESCU, L., G., CRUCERU, M., Evaluation of structural changes that occur during the combustion of coal of Oltenia basin at Turceni power plant. 13th International Multidisciplinary Scientific GeoConference SGEM 2013, 16-22 June 2013, Albena, Bulgaria, Science and Technologies in Geology, Exploration and Mining Proceedings, Vol.I., p. 39.
20. ABAGIU, T., A., POPESCU, L., G., PREDEANU, G., CAZALBAȘU, R., ANGHELESCU, L., Use of power plant bottom ash as granular aggregate to manufacturing of lightweight heat resistant concretes, 2nd International Conference ROMCEN Production and use of fly-ash in construction. Present and perspectives, Calimanesti, Romania, 24-25 June 2014.
21. TERZIĆ, A., ANDRIĆ, L., PETROV, M., RODOJEVIĆ, Z., MILČIĆ, L., Investigation of high temperature behaviour and sintering mechanism of fly ash based concretes, Romanian Journal of Materials, 44 (3), 2014, p. 213.
22. VELEA, T., MARA, L., ANGER, I., ANDREI, B., ENACHE, L., BADILITA, V., STOICIU, F., GHITA, FRUTH-OPRISAN, V., MUNTEANU, C., Cercetări privind cenușa de la termocentrala CET Govora, caracteristici fizico-chimice și structurale. Direcții de utilizare în construcția drumurilor, 2nd International Romanian Conference Production and Utilisation of Fly Ash in the Construction Industry, Calimanesti, June 2014.
23. FEUERBORN, H., J., Management and Standardisation of Coal Combustion Products in Europe, 2nd International Romanian Conference Production and Utilisation of Fly Ash in the Construction Industry, Calimanesti, June 2014.
24. POPESCU, N., Cenușa zburătoare – o materie prima pentru dezvoltare durabilă, 2nd International Romanian Conference Production and Utilisation of Fly Ash in the Construction Industry, Calimanesti, June 2014.
25. ISO 7404-2, Methods for the petrographic analysis of coal. Part 2: Method of preparing coal samples. International Organisation for Standardisation – ISO, Geneva. 1994, 2 p.
26. *** ISO 7404-5, Methods for the petrographic analysis of coal. Part 3: Method of determining maceral group composition. International Organisation for Standardisation – ISO, Geneva, 1994, 6 p.
27. SÝKOROVÁ, I., PICKEL, W., CHRISTANIS, K., WOLF, M., TAYLOR, G., H., FLORES, D., Classification of huminite—ICCP System 1994, International Journal of Coal Geology, 62, 2005, p. 85

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