CEST 2017

15th International Conference on Environmental Science and Technology

Rhodes, Greece, 31 August to 2 September 2017

Geotechnical Properties of Products of Alternative Fuel Combustion and Their Co-firing with Hard Coal in the Context of Waste Management

Stefaniak S.[1], Kmiecik E[2], Twardowska I.[1]*

[1] Institute of Environmental Engineering of the Polish Academy of Sciences, 41-819 Zabrze, Poland

[2] AGH University of Science and Technology in Krakow, Poland

**Corresponding author:*

e-mail:irena@ipis.zabrze.pl; Tel +48323716481; Fax: +48322717470

Abstract Efforts directed to reduction of GHG emissions lead to the introduction to the coal-based power industry of new firing/co-firing technologies and alternative fuels. This resulted in the formation of combustion products with new properties that may affect the reuse of these wastes or/and pose hazard to the environment. One of the powerplant fly ash (FA) reuse options is its application as dense mixture with water for backfilling mine workings or in engineering constructions. In this comparative study, geotechnical properties of four groups of FA were evaluated: (I) from hard coal combustion in conventional pulverized coal boilers, as disposed coal ash (C-PCA) and freshly generated FA without (C-PFA) and with SNCR installations for NOx reduction (NC-PFA); (II) from co-firing of coal with biomass in pulverized coal boilers (BC-PFA); (III) from coal (C-FFA) or biomass combustion in fluidized-bed boilers (B-FFA); (IV) from co-firing of process gases with coal in pulverized coal boilers (GC-PFA). The transportability, bonding, solidification properties and resistance to axial compression and re-wetting of dense mixtures were evaluated by volumetric density, fluidity, water retention capacity, bonding time, solidification time, resistance to axial compression and slakening parameters. Calcareous C-FFA > B-FFA appeared to display the best geotechnical properties. Other materials can be aligned in order BC-PFA>GC-PFA>NC-PFA>C-PFA>C-PCA, though showing much weaker geotechnical properties than FFA.

Keywords: coal/biomass combustion fly ash; pulverized coal/fluidized-bed combustion; mine workings backfilling; fly ash dense mixtures, geotechnical properties

1. Introduction

Decisions of the European Commission on the effort of Member States to reduce their greenhouse gas (GHG) emissions aimed at the attenuation of climatic changes (EC, 2009, 2015) lead to the introduction to the coal-based power industry of new firing/co-firing technologies and alternative fuels. Co-firing of different alternative fuels with coal as a source of power gains in growing popularity due to potential, however not always indisputable positive environmental and economic effects (e.g. Judl et al, 2014; Stanek and Białecki, 2014; Röder et al., 2015). These effects are often estimated as a net reduction of CO2 emission, while alternative fuel availability in the required amounts, transportation costs, environmental hazards at acquiring and transport of these fuels are often neglected. Co-firing of the alternative fuels with coal is aimed at the mitigation of climate changes through partial replacing coal with low-emission fuels, or with renewable energy sources, along with profitable recycling of combustion products. Up to now, the most common component used for co-firing, is biomass, being obtained either from purposeful cultivation of fast–growing plants (e.g. Salix sp.) or generated as a by-product in agriculture, forestry or food industry (Baxter, 2005; Bertrand et al., 2014). Other such potential fuel is gas, either natural or off-gas from industrial processes (Stanek and Białecki, 2014; Stamford and Azapagic, 2014 Werner et al. 2015). To achieve the best co-firing efficiency, different combustion technologies have been used, such as a change from pulverized coal boilers to fluidized-bed ones. Both modifications of fuels, and combustion processes and parameters have resulted in the formation of combustion products with new properties that may affect the reuse of these wastes or/and pose hazard to the environment. One of the powerplant fly ash (FA) major bulk reuse options is its application as a dense mixture with water for backfilling mine workings or as a common fill in engineering constructions. In this comparative study, geotechnical properties of dense mixtures of four groups of FA from coal co-combustion with alternative fuels, of primary importance for these applications were for the first time assessed and evaluated: transportability, bonding, solidification, resistance to axial compression and slakeability of solidified mixtures due to re-wetting.

2. Material and Methods

2.1. Material

For the study, representative samples of a material from the routine full-scale combustion of alternative fuels with hard coal in different power plants in Poland was used. The studied material comprised combustion residuals:(I) from hard coal combustion in conventional pulverized coal boilers - weathered coal ash of different age (C-PCA), as well as freshly generated fly ash without (C-PFA) and with selective non-catalytic reduction (SNCR) installations for controlling NOx (NC-PFA); (II) from co-firing of coal with biomass in pulverized coal boilers (BC-PFA); (III) from coal (C-FFA) or biomass combustion in fluidized-bed boilers (B-FFA); (IV) from co-firing of process gases with coal in pulverized coal boilers (GC-PFA).

In total, 14 representative samples from 8 power and thermal plants in Poland (coded with different numbers) were collected.

2.2. Methods

The transportability, bonding, solidification, resistance to axial compression and slakeability properties of solidified dense mixtures were evaluated by volumetric density, fluidity, water binding, bonding time, solidification time, resistance to one-axial compression and slakeability/resistance to re-wetting parameters. The geotechnical testing was performed at the Laboratory of the Faculty of Mining and Geology of the Silesian University of Technology in Gliwice, Poland. The studies were conducted under the conditions mimicking those in the deep mine workings, with the use of dense mixtures at water/solid ratio W/S = 1:1, with the preceding seasoning at a climate chamber at t0=250C and moisture content 100%. Mixture density was assessed as a mass to volume ratio; mass was measured on electronic balance and volume by pycnometer. Fluidity was determined with the use of a Ford viscosity cup as a diameter of a mixture cake at the glass plate. The amount of unbound water was measured in a measuring vessel as a resultant thickness of supernatant water layer calculated as percent by volume of a primary sample. Bonding time was determined as the time of achievement by a sample of bearing capacity 0.5 MPa measured with the use of a Vicat camera. Solidification time was measured on cylindrical samples of 100 mm diameter and 40 mm height as the time between penetration of a Vicat camera needle into the sample to the maximum depth of 38 mm at the beginning and no more than 2 mm at the end of the measurement. The tests of resistance to one-axial compression were performed after 7, 14 and 28 days of a cylindrical sample seasoning in a climate chamber. For the testing, LRuE-2 apparatus with digital data read-out and logging was used, and a mean value of measurements was calculated. Slakeability of solidified dense mixtures is an important parameter characterizing environmental behaviour of a solidified material. It was assessed as a percent loss of resistance to one-axial compression of a solidified sample seasoned in a climate chamber for 28 days and next submerged in water for 24 hours.

3. Results and Discussion

3.1. Volumetric density and fluidity

Table 1. Fluidity and Volumertric density of water/FA dense mixtures

Group No.	Sample kind and No*).	Fluidity, [mm]	Volumetric density [kg/m3]
I	C-PCA [16,1,2, 15]	340-410	1174-1298
	C-PFA [28]	270	1275
	NC-PFA [31,44]	340-365	1268-1324
II	BC-PFA [33, 42]	350-390	1298-1305
III	C-FFA [19, 39]	275-345	1350-1431
	B-FFA [10, 17]	240-375	1391-1402
IV	GC-PFA [26]	240	1340

*) Sample numbers mean material from different installations of the similar kind at the studied power plants Samples C-PCA [16,1,2, 15] mean disposed coal ash 30-, >10-, <10, and 0 years old, respectively.

Coal ash from hard coal combustion had the lowest density. By contrast, FA from fluidized-bed boilers had distinctly greater density (1350-1431kg/m3) than that from pulverized coal boilers (1268-1340 kg/m3). Fluidity of dense mixtures of C-PFA/C-PCA increased with waste age, from 270 mm for freshly generated waste to 410 mm for weathered material. The lowest fluidity (240-275 mm) showed GC-PFA and calcareous B-FFA/C-FFA. Fluidity of dense mixtures of ash from other combustion technologies and fuels ranged within medium values (340-390 mm)

.3.2. Water retention capacity

The amount of unbound water after dense mixture solidification ranged from 12% to 50%; Coal-ash mixtures showed low water retention capacity, in particular weathered material, where the unbound water accounted for 41-50%. Freshly generated C-PFA showed about 2-fold higher water retention capacity. The least amounts of unbound water (12%) were observed in the calcareous B-FFA; somewhat higher unbound water amounts (15%) occurred in NC-PFA and GC-PFA. Other mixtures of combustion residuals, both from pulverized coal boilers and fluidized bed boilers showed lower retention capacity and amounts of unbound water at the level of 25-27%.

Bonding time

Bonding time of the studied dense mixtures accounted from 2 days to 5 days; older PCA waste were bound at a shorter time, while freshly generated dense mixtures C-PCA/C-PFA underwent bonding during 4 days. Dense mixtures based on BC-PFA displayed similar bonding time (3.5-4 days), while C-FFA and B-FFA mixtures were bound over the shortest period (2-3 days).

Solidification time

Solidification time ranged from 3 days (C-FFA) to 6 days (C-PCA). Weathering processes affected adversely solidification time that for weathered C-PCA reached 5.5-6 days, while for freshly generated C-PCA, C-PFA and GC-PFA it accounted for 5 days. Dense mixtures of coal and biomass combustion residues BC-PFA undergo solidification in 4-5 days, residues from biomass combustion in fluidized-bed boilers solidified in 3.5-4.5 days, while residues from calcareous fluidized-bed boilers (C-FFA) needed for solidification the shortest time (3 days).

3.5. Resistance to axial compression

The coal-ash based dense mixtures of different age retained sandy or plastic consistence during the whole period of seasoning, in particular weathered older PCA waste. Freshly generated PFA waste showed somewhat better resistance to one-axial compression, up to a value Rc28=0.13 MPa that was considerably lower than for FFA (Fig. 1). Freshly generated fly ash from coal combustion in pulverized coal boilers (C-PFA) displayed constant very low values Rc= 0.07-0.08 MPa, similarly to NC-PFA, BC-PFA or GC-PFA (Fig. 2). Dense mixtures based on fly ash from fluidized–bed boilers (FFA) showed many-fold higher resistance to one-axial compression, both in case of coal or biomass combustion (Rc= 0.523-2.653 MPa) (Fig. 3).

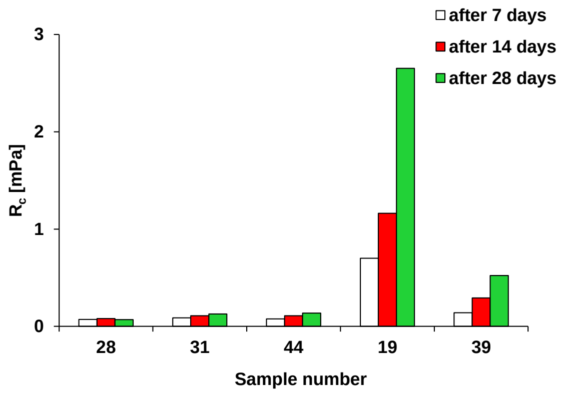

Figure 1. Resistance to one-axial compression (Rc) of dense mixtures based on fly ash from coal combustion in pulverized coal boilers (28 – C-PFA; 31,44 – NC-PFA) and in fluidized-bed boilers (19, 39 – C-FFA)

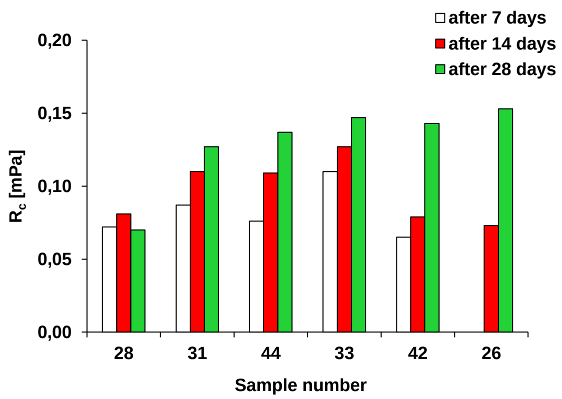

Figure 2. Effect of fuel on the resistance to one-axial compression (Rc) of dense mixtures based on fly ash from coal combustion in pulverized coal boilers (28 – C-PFA; 31,44 - NC-PFA; 33, 42 – BC-PFA; 26 – GC-PFA)

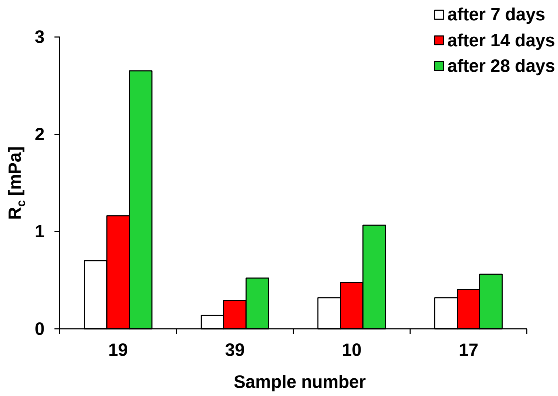

Figure 3. Effect of fuel on the resistance to one-axial compression (Rc) of dense mixtures based on fly ash from coal combustion in fluidized-bed boilers (19, 39 – C-FFA; 10, 17 – B-FFA)

3.6. Slakeability of solidified dense mixtures

Treatment of solidified dense mixtures of C-PCA, C-PFA and GC-PFA with water for one day resulted in their thorough slackening and decomposition. The NOX control at SNCR installations caused diverse effect on slakeability of solidified NC-PFA mixtures – from 100% to about 40%. Similarly, the slakeability of dense mixtures based on residues from co-firing of coal with ~10% of biomass in pulverized coal boilers (BC-PFA) appeared to reach from 14% to 100% of the sample. By contrast, slackening of solidified dense mixtures based on residues from combustion in fluidized-bed boilers appeared to be much lesser, up to 20-50%; lower resistance to wetting showed C-FFA - fly ashes from coal combustion (40-50%) than B-FFA – fly ashes from biomass combustion.

3.7. Overall effect of temporal transformations, combustion technology and kind of fuel on the geotechnical properties of combustion residues

The study showed that weathering transformations, technology of combustion and a kind of fuel considerably affect the geotechnical properties of powerplant wastes, reused among others for filling disused workings in deep mines, and in engineering constructions. Due to the determining effect of CaO content, calcareous FA from the fluidized-bed boilers in particular FFA from combustion of hard coal C-FFA > B-FFA appeared to display the best geotechnical properties. Other materials can be aligned in order BC-PFA>GC-PFA>NC-PFA>C-PFA, though showing much weaker geotechnical properties than FFA. The longest solidification time, plasticity in the entire seasoning period and the total decomposition at re-wetting, showed dense coal ash mixtures (C-PCA), in particular weathered ones. Also silicate FA of class F from coal combustion in pulverized-fuel boilers (C-PFA) showed similarly weak geotechnical properties. Every modification of a combustion process or a fuel caused certain improvement of geotechnical parameters of silicate class F fly ash, however much weaker than these of FA from the fluidized-bed boilers.

4. Conclusions

Both the technology of combustion and the fired fuel affect, although to the different extent, geotechnical properties of the products of combustion and co-combustion of alternative fuels with hard coal. The technology of firing/co-firing appeared to have the strongest effect on these properties, while the kind of fuel was of a differentiated importance, depending upon the CaO share. In general, the study showed a considerable alterations of co-combustion product properties. For these reasons, besides the assessment of an extent of GHG reduction resulting from the application of new fuels and technologies of power generation, the assessment of recycling properties and life cycle impact of the residues formed in these processes onto all potentially threatened compartments of the environment is a prerequisite of the sustainable development.

References

Baxter L. (2005), Biomass–coal co-combustion: opportunity for affordable renewable energy, Fuel, 84,1295-1302.

Bertrand V., Dequiedl B., Le Cadre E. (2014), Biomass for electricity in the EU-27: Potential demand, CO2 abatements and breakdown prices for co-firing, Energy and Policy, 73, 631-644.

EC – European Commission, (2009). Decision 406/2009/EC of 23 April 2009 on the effort of Member State to reduce their greenhouse gas emission to meet the Community's greenhouse gas emission commitments up to 2020 (Effort Sharing Decision, ESD), Official Journal L 140, 5.6.2009, 136-148.

EC – European Commission, (2015), Climate Action. Effort Sharing Decision. Last update 24.09.2015, http://ec.europa.eu/clima/policies/effort/index_en.htm

Judl J., Koskela S., Korea T., Karvosenoja N., Häyrinen A., Rantsi J. (2014), Net environmental impacts of low-share wood pellet co-combustion in an existing coal-fired CHP (combined heat and power) production in Helsinki, Finland,. Energy, 72, 844-851.

Röder M., Whittaker C., Thornley P. (2015), How certain are greenhouse gas reductions from bioenergy? Life cycle assessment and uncertainty analysis of wood pellet-to-electricity supply chains from forest residues, Biomass and Bioenergy, 79, 50-63.

Stanek W., Białecki R. (2014), Can natural gas warm the climate more than coal? Fuel, 136, 341-348.

Stamford L, Azapagic A. (2014), Life cycle environmental impacts of UK shale gas, Applied Energy, 134, 506-518.

Werner A.K., Vink S., Watt K., Jagals P. (2015), Environmental health impacts of unconventional natural gas development. A review of the current strength of evidence, Science of The Total Environment, 505, 1124-1141.

Acknowledgments

This study was supported financially by the grant of the Polish National Center of Science NCN No. UMO-2011/03/B//ST10/06128 (2012-2015).

A contribution of Dipl. tech. Magdalena Kaczorowska to conducting research and preparation of this paper is highly appreciated