Modeling Approach of the Experiment: Waste Reuse of the Jerada Thermal Power Plant (Morocco)

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Abstract. The main objective of this work is to find a model mathematical statistics which will justify the valorization principle of the FA (Fly Ash) and BA (Bottom Ash), which represent the most remarkable solid waste of the thermal power plant in the eastern region of Morocco (in the Jerada city).

For this, we worked on the use of FA and BA as a raw material for performance bricks. First, compression tests and chemical requirements were used to evaluate the pozzolanic activity index according to ASTM (American society for testing material) which is about 89,75%. Indeed, we have effectuated a statistic modeling by the method of the experiences plans where we have chosen as a response the compressive strength. The results of our new by-product (10% of FA+BA and 90% of cement), gave a good response to our plan, about 24,2 MPa. Secondly, we added this new by-product with the clay to produce the compressed bricks fired according to a new experimental plan, where we found that the most resistance to compression equal to 3,12 MPa, in which a minimum quantity of clay of 50% (by the total mass of 1 kg), were used.

In order to control these residues, our results show that our mathematical model can be adapted to new entrepreneurs who want to invest in bricks manufacture using these by-products to contribute to efforts of environmental pollution reduction.

Keywords: Fly Ash · Bottom Ash · Waste · Coal · CCRs · Pozzolanic By-product · Boiler · Valorization

1 Introduction

1.1 Coal Combustion Residues (CCR)

The thermal power plants are globally criticized for generating large amount of solid wastes often with a potential environmental impact. Coal Combustion Residues (CCRs), also known as Coal Combustion Products, are the wastes from thermal power stations. These include fly ash (FA), bottom ash (BA), and boiler slag (BS), fluidized

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bed combustion ash (FBCA), flue gas desulfurization (FGD). Current worldwide annual production of coal combustion products is estimated to exceed 600 million tonnes, being highly influenced by China's explosive economic trends and lack of data for the underdeveloped areas of that Country [1]. Estimation about production and reutilization of CCRs by major producer countries is reported in Table 1 [2]. Recycling, being one of the strategies in minimization of waste, offers three benefits: (i) reduce the demand upon new resources, (ii) cut down on transport and production energy costs and (iii) use waste, which would otherwise be lost to landfill sites [10]. The reutilization and/or recycle of such by-products has been studied for decades in many areas and research and proposals are still developed in several countries (Table 2), but with remarkable differences as far as added-value is concerned.

Table 1. Production and utilization of CCRs in major producer countries [2].

Country	CCRs production (10^3 tonnes)	CCRs utilization (10^3 tonnes)	Utilization rate (%)	Year	References
USA	117,289	61,1	52,05	2015	[3]
China	350	203	58,0	2010	[1]
India	105	28,3	27,0	2005	[4]
EU15	48,327	47,749	91,0	2010	[5]
Australia	12,1	4,8	40,0	2015	[6]
Japan	11	10,6	97,2	2006	[7]
Canada	6,846	1,761	26,0	2010	[8]
Total	**650,562**	**357,31**	**54,92**		

Table 2. Particular reuses and recycles of CCRs in different countries [2].

Country	CCR type	Application
India	CCRs	Various brick productions
Japan	Ashes	Development of artificial Z-sand for Civil Engineering
USA	FA	Non-fired bricks
Australia	FA	1000° fired bricks
USA	FA	Fired bricks
Taiwan	FA	Fired and non-fired bricks using ashes mixed with pond sludge
Turkey	FA	Fired bricks
Russia	Ashes & mining wastes	Construction ceramic materials
Turkey	FA, BA, furnace slag	Cement and fine sand replacement in concrete
USA	BA & FA	Enhancement of rammed earth constructions
Sweden	BA	Light fill material
Spain	FA & slag	Light weight aggregates
Netherlands	FA	Bricks and concrete

From where the valorization of the waste is a strategic gait for all country of the world, it is about the transformation of a residual to a wealth. The valorization of CCRs is indeed very common in the cement industry as raw material in the production of the cement clinker, interground with the clinker, or blended with the finished cement [3], [9]. This procedure is profitable for our environment and it has remarkable advantages. For our study, the objective is to reuse the FA and BA of the coal power plant of Jerada city and to find efficient uses for this material that causes some problems for the thermal power plant in term of cost of evacuation as well as the environmental level.

At the time of this work, a modeling has been made to define this material and its mechanical behavior with clay and cement, and then several uses have been developed and have been tested.

1.2 Preliminary Study of the CCR

Properties of the Bottom Ash (BA). Very abrasive material, flow of 1 ton per hour, maximal granulometry at the exit of the boiler ≈350 mm and density of ≈1.967 g/l. The bottom ash is a residual resulting from the combustion of coal, collected in the ashtrays, it takes on the appearance of dough carried to the red that is due to the silica melted to a temperature of 1450 °C, the best is coal presenting the less bottom ash [10]. These BA, illustrated in the Fig. 1, are composed of vitrified fragments with sharp edges whose dimensions vary in large measures according to the type of coal.

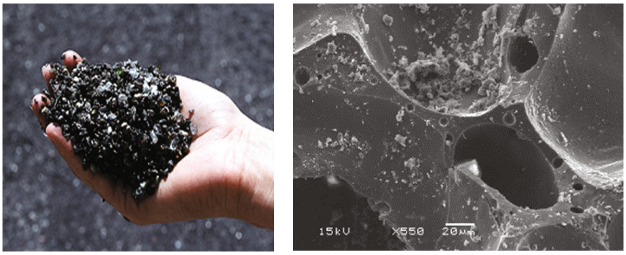

Fig. 1. Form and SEM (Scanning Electron Microscopy) image of sampled BA [2].

Properties of the Fly Ash (FA). Very abrasive, dusty material, flow of 4 tons per hour, maximal granulometry at the exit of the boiler ≈35 µm, density of ≈1.967 g/l. The fly ashes are composed of the spheroidal particles very fine, their diameter being in the order of 10 to 35 microns, see Fig. 2, the finest are sucked by the emission ventilators, the biggest are collected in the dust collectors for the tranches number 1 and 2, and for the 3rd tranche they are collected in the electrostatic filter then evacuated to the soot channel.

2 Results and Discussion

2.1 Data Prepared for Modeling

In the ASTM standard [12], the pozzolana are defined like the siliceous materials or aluminosilicate witch does not possess in themselves binding properties but that reacts chemically, in finely divided form and in the presence of moisture, with the calcium hydroxide at ordinary temperature to form compounds having binding properties. According to the standard, a material has the characteristic of a pozzolana if:

- Its chemical composition checks: **$AL_2O_3 + SiO_2 + Fe_2O_3 > 70\%$**
- Its activity indication **I** is: **$0,67 < I < 1$.**

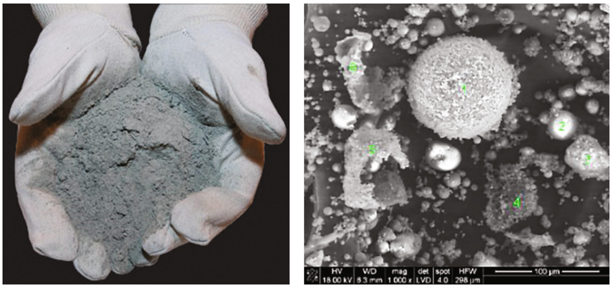

Fig. 2. Form and SEM (Scanning Electron Microscopy) image for fly ash (FA) sample, at 1000x magnification [11].

Chemical Composition of the CCRs. The following Table 3 gives a summary of the chemical composition of the sample where we can apply the following analysis: According to the standard ASTM, the fly ash present themselves in two classes (C class or F class). The only difference between the two classes is the percentage of calcium oxide. For the C class the percentage of calcium oxide is higher than 20%. For our sample the calcium content is low (<1%), therefore it is fly ash of F class.

Table 3. Chemical composition of the sample studied.

Components	%	According to standard
Silicon dioxide SiO_2	50,34	ASTM D6349
Aluminum oxide Al_2O_3	26,54	ASTM D6349
Iron oxide Fe_2O_3	12,87	ASTM D6349
Calcium oxide CaO	0,87	ASTM D6349
Magnesium oxide MgO	0,05	ASTM D6349
Sodium oxide Na_2O	2,18	ASTM D6349
Potassium oxide	1,40	ASTM D6349
Manganese oxide MnO_2	1,16	ASTM D6349
Titanium oxide TiO_2	3,04	ASTM D6349
Phosphorus pentoxide	0,14	ASTM D6349
Sulfur trioxide SO_3	1,41	ASTM D5016

2.2 Verification of Compatibility with the Standard ASTM C618

Requirements of the Standard. Our sample must satisfy the requirements defined in the ASTM standard C 618 (that analyzes the CCRs reuse) these requirements are:

- The organic matter percentage for the F class, (Loss on Ignition ratio) LOI <6%;
- The percentage of (silicon oxide + aluminum oxide + iron oxide) >70%;
- The percentage of sulfur trioxide <1.5%;
- The total humidity <3%;
- The percentage of particles, less than 45 μm in diameter, must be >75%.

Verification of the Compatibility of Our Sample. According to the Table 3 of the analyses, the sum of the percentages of the three components (the silicon oxide (SiO2), the aluminum oxide (Al2O3) and the iron oxide (Fe2O3)) is equal to: 50.34 + 26.54 + 12.87 = 89.75%. So it's >70%.

- The percentage of sulfur trioxide (SO3) in our sample is: 1.41% (<1.5%);
- The total humidity of our sample is: 2.5% (<3% definite in the Standard);
- The Loss on Ignition ratio of the sample is: 10% (>6% definite in the Standard).

2.3 The Mathematical Modelling by the Realization of the Experimental Plan 2^2

To model the use of this waste in order to find the function that binds the response to the factors by a general expression in the following form:

$$Y = a_0 + a_1x_1 + a_2x_2 + \ldots + a_nx_n + \sum\nolimits_{i,j=1}^{n} a_{ij}x_ix_j + \sum\nolimits_{\substack{i,j=1 \\ i \neq j \neq k}}^{n} a_{ijk}x_ix_jx_k + \ldots \tag{1}$$

We already have the tests and measurements necessary for this present work, see [2], now we will try to find a mathematical model that will organize us to get a high performance bricks from this CCRs. Indeed, we have two factors, then this function becomes in the following form:

$$Y = a_0 + a_1x_1 + a_2x_2 + a_{12}x_1x_2 \tag{2}$$

With:

- Y: is the response in the point of the chosen composition;
- x_1, x_2: are the respective contents of cement and CCRs;
- a_0, a_1, a_2: are the unknown coefficients.

If the responses and the factors are known, we pass to determine the coefficients.

$$\begin{cases} Y_1 = a_0 - a_1 - a_2 + a_{12} \\ Y_2 = a_0 + a_1 - a_2 - a_{12} \\ Y_3 = a_0 + a_1 - a_2 + a_{12} \\ Y_4 = a_0 + a_1 + a_2 + a_{12} \end{cases} \quad (3)$$

Therefore we find that: $a_0 = 14.525$; $a_1 = -8.675$; $a_2 = -0.475$; $a_{12} = 0.525$. Hence the mathematical model becomes:

$$\boldsymbol{Y} = 14.525 - 8.675\boldsymbol{x}_1 - 0.475\boldsymbol{x}_2 + 0.525\boldsymbol{x}_1\boldsymbol{x}_2 \quad (4)$$

This model allows to calculate all the responses in the study field; it is sufficient to assign values to the levels x1 and x2 to obtain immediately the best value of the adequate response. In the same way carried out in the previous experiment plan, our mathematical model of the second plan (Clay and (Cement + CCR) mixture) becomes as the following:

$$\boldsymbol{Y} = 2.8075 - 0.0775\boldsymbol{x}_1 - 0.2625\boldsymbol{x}_2 - 0.0275\boldsymbol{x}_1\boldsymbol{x}_2 \quad (5)$$

3 Conclusion

The experimental plan serves to optimize the number of experiments to be realized and to determine the mixing model, that lets to calculate all the responses in the study field of without experiencing. It is enough to attribute values to cement and CCRs contents to immediately obtain the value of the response. In our case, it can be seen from the results obtained from the compression test that the sample, which is more resistant, is the sample of 10% of CCRs and 0.33 (water/mixture) report. While in the last experiment performed, we constructed the fired bricks on the basis of the clay and the material constructed in the first experiment, we found that the most resistant bricks were those in which we used a minimum volume of water 581 cm^3 and a minimum amount of clay 50%.

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