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Recycling coal fly ash and coal bottom ash from Moroccan thermal power plant in concrete manufacturing

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Abstract

The aim of this investigation is to assess the use of fly ash and bottom ash generated from Taqa Morocco thermal power plant as replacement of cement and coarse aggregate, respectively in concrete manufacturing. Firstly, characterization of these wastes from thermal power plant was conducted in order to determine their chemical and physical compositions. Further experiments were carried out by replacing cement with fly ash which was varying in percentages (0%,10%, 20%, 30% and 40%). In the same sense, various volume fractions of natural coarse aggregate (0%, 20%, 40%, 60%, 80%, and 100%) were replaced by the same volume of coal bottom ash. The results showed that the slump flow of fresh concrete was slightly decreased when fly ash was replaced 10%, 20% and 30% of cement. The same evolution obtained for mixture containing bottom ash as a replacement of normal aggregate. Moreover, it also showed that compressive strength of concrete 'A' did not changed significantly when cement was replaced with 10%, 20% and 30% of fly ash. But incorporating fly ash up 30% has a negative impact on compressive strength . However, in case of concrete 'B', the compressive strength of concrete 'B' did not affected until 80% of bottom ash but it decreased when bottom ash was used as total replacement of coarse aggregate. Overall, fly ash and bottom ash can be effectively used in concrete manufacturing.

1. Introduction

Coal, the second source of primary energy (roughly 30%), is mostly used for power generation (over 40% of worldwide electricity is produced from coal). However coal combustion generates a large amount of coal ash. This latter includes a number of by-products produced from burning coal, including: fly ash, bottom Ash, boiler Slag and flue gas desulfurization material. Fly ash (FA) and bottom ash (BA) are the major solid waste of coal combustion. Recently, the management of these wastes is a challenge for environment because the problem of securing the site of landfill occurred. Interest in recycling these by-products, particularly FA and BA increased, because their occurrence affects the efficient management of the land due to limited landfill sites. Bottom ash and fly ash have physical and chemical characteristics that make them suitable as a building material [1].

Many researchers studying the effect of replacing cement partially by fly ash in concrete manufacturing [2,3,4]. Fly ash is also used as an additional material in manufacturing of portland cement concrete [5,6]. Other researchers studied the environmental benefits of incorporating fly ashes in concrete as cement replacement[7]. They found that the use of fly ashes can reduce the CO_2 emissions compared with typical concrete. In the case of bottom ash, It is showed in the literature that the grinding bottom ash can effectively replace up to 20% of cement without reducing the strength class of the concrete [8]. Also it was used to improve workability in mortar cement [9].

In Morocco, the studies conducted on coal ashes are related either to its use as adsorbent in wastewater treatment [10] or in removing dyes [11]. But, the incorporating of coal ash in building material, is very limited. El moudni et al. studied the possibility of using fly ash and bottom ash in road pavement [12].

The objective of the current research work was to investigate the effects of using bottom ash and fly ash as replacement of coarse aggregate and cement, respectively, on workability and the compressive strength properties of concrete. They were then compared with those of normal concrete. The materials chosen were carefully studied with respect to their properties such as fineness modulus, specific gravity and chemical composition. The long-term durability properties of the concrete made partially by fly ash and bottom ash may be analyzed in future study.

2. Material and Methods

2.1.Materials

2.1.1.Coal fly ash and coal bottom ash

Coal ash samples namely fly ash and bottom ash were collected from Taqa Morocco thermal power plant. Figure 1 shows the visual aspect of bottom ash and fly ash.

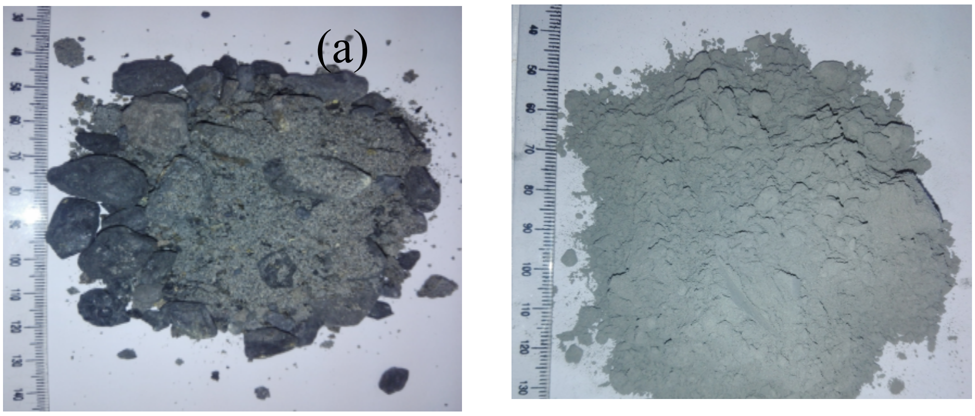

Figure 1: Visual aspect of bottom ash (a) and fly ash (b)

Table 1: Chemical composition of bottom ash and fly ash

Constituents	Bottom ash wt%	Fly ash wt %
SiO_2	45.64	45.17
Al_2O_3	18.2	19.67
Fe_2O_3	8.74	7.51
CaO	8.18	7.77
MgO	3.8	4.07
K_2O	2.01	1.61
MnO	0.09	0.07
TiO_2	0.98	1.24
P_2O_5	0.98	1.27
SO_3	-	-

The chemical composition of Bottom ash and fly ash are depicted in table 1. As shown in table 1, the major components of FA are silica, iron, alumina. sum of SiO_2, Al_2O_3, and Fe_2O_3 of FA reached 72.35 % in the composition, indicating that it could be classified as pozzolan material . So, FA has a potential use as an additive to cement-based composite owing to its pozzolanic activity. As regard BA, it is mainly composed of silica, alumina, and iron. Sum of SiO_2, Al_2O_3, and Fe_2O_3 is about 72.58%. Which means that both fly ash and bottom ash verify the standard requirement ASTM for the used materials in concrete [13].

2.1.2.Cement

The ordinary Portland cement used in this study fulfilled the requirements of NM 10.1.004 [14]. Its chemical composition was mesured by X-ray fluorescence (XRF) spectrometer. As regards for its physical characteristics were taken from its technical sheet. From the data (Table 2), it seems that initial and final setting times of cement are 180 min and 210 min, respectively.

2.2.2.Sand

The sand used in this study was conforming to NM 10.1.149. The specific gravity, water absorption and fineness modulus of sand, bottom ash, fly ash and coarse aggregate were mesured in laboratory .The results are presented in Table 3.

Table 2: Chemical composition and physical Characteristics of cement

Chemical composition wt %		**Physical characteristics**
SiO_2 **%**	21.3	Initial setting time 180 min
Al_2O_3 **%**	5.58	Final setting time 210 min
Fe_2O_3**%**	3.4	Specific gravity 3.15
CaO**%**	62	Compressive strength 7 days 30 MPa 28 days 40 MPa
MgO **%**	1.85	
K_2O **%**	2.1	
TiO_2 **%**	0.3	
SO_3 **%**	2.41	

Table 3: Physical properties of CBA, CFA, sand and coarse aggregate

	Specific gravity	Water absorption%	Fineness
Coarse aggregate	2.62	0.6	6.4
Sand	2.68	6.4	2.77
BA	1.88	6.2	-
FA	2.3	3.45	-

2.2.Mixture concrete

Concrete mixtures were tested for their fresh and hardened characteristics. The details of mix proportions for concrete A and concrete B are given in table 4 and table 5, respectively. The mixture were designed to evaluate the effects of fly ash and bottom ash on concrete. Cement was replaced with four different volume fractions (10%, 20%, 30%, and 40%) of fly ash and coarse aggregate was replaced with different percentages (20%, 40%, 60%, 80%, and 100%) of bottom ash. Labels 'A' and 'B' refer to concrete A and concrete B, respectively. Firstly and before any experiment, bottom ash was dried to eliminate excess of water which can affect the W/C ratio during the concrete mixture.

The experiments were conducted in a 60 L capacity mixer according to the following procedure :

1) All materials are introduced in the mixer except water
2) They were mixed for 3 min
3) Water was then added in the mixer
4) All materials including water were mixed for 5 min again

Table 4: Mix proportion of 1 m^3 concrete 'A' for W/C= 0.53

Concrete A					
	Water	Sand	Cement	Fly ash	Coarse aggregate
A0(Control)	187	695	350	0	1165
A10	187	695	315	26	1165
A20	187	695	280	51	1165
A30	187	695	245	77	1165
A40	187	695	210	102	1165

Table 5: Mix proportion of 1 m^3 concrete 'B' for W/C= 0.53

Concrete B					
	Water	Sand	Cement	Bottom ash	Coarse aggregate
B0(Control)	187	695	350	0	1165
B20	187	695	350	167	932
B40	187	695	350	335	699
B60	187	695	350	502	466
B80	187	695	350	669	233
B100	187	695	350	834	0

3. Results and discussion

3.1.Workability

Figure 2 shows a typical slump test result on fresh concrete A and fresh concrete B. The workability of mortar mixes was measured by performing slump test according to Moroccan Standard NM 10.1.061 [15]. Figure 3 shows the effect of coal fly ash as a replacement of cement in concrete mixtures on slump values. Slump value of control concrete mixtures was 40 mm for concrete 'A' (A0) . This is classified as S1 in NM 10.1.008 [16]. From the obtained result, it seems that slump values changed slightly in the mixtures A10 and A20. But up to 30% replacement level, fly ash concrete mixtures of concrete 'A' showed more decrease in slump values as compared to the mixture A0. Hence it's difficult to maintain the initial ratio W/C = 0.53. This is due to the water absorption of fly ash is higher than the water absorption of cement . This finding has an agreement with Ikotun et al. [17].

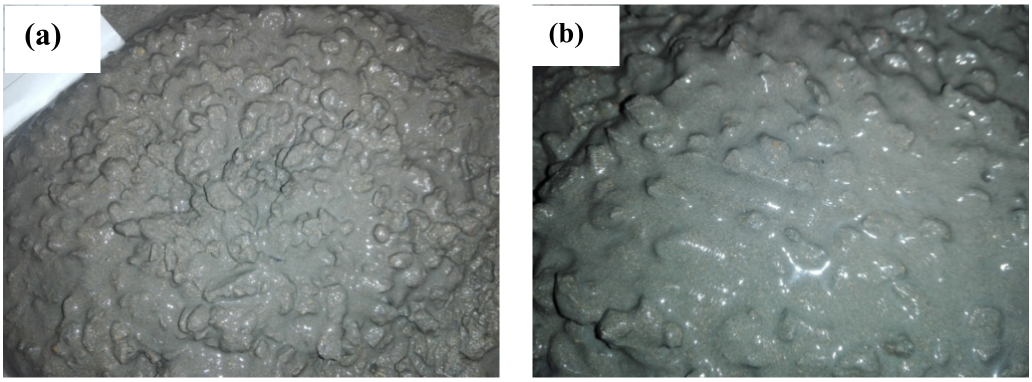

Figure 2: Mixture of concrete A made partially by fly ash (a) and concrete B made partially by bottom ash (b)

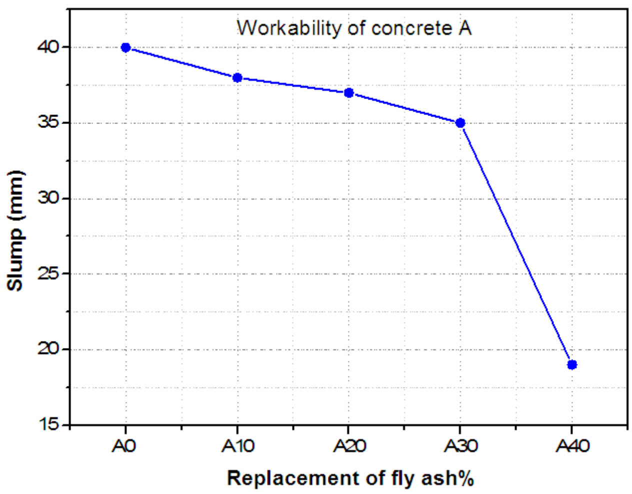

Figure3: Effects of FA on flow characteristics of fresh concrete

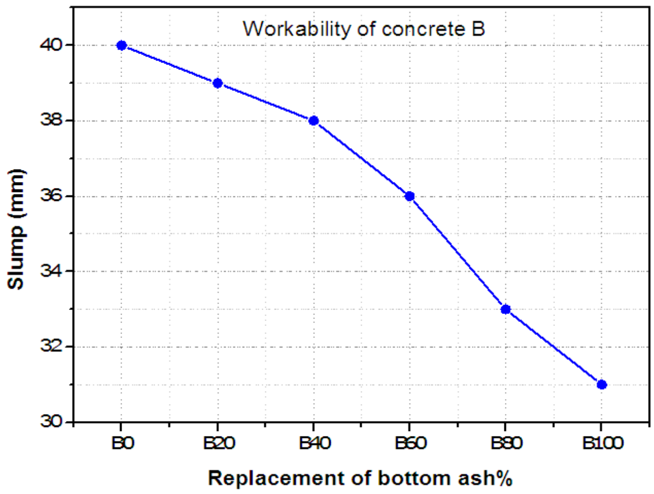

Figure4: Effects of BA on flow characteristics of fresh concrete

From figure 4, It can be seen that the slump value of coal bottom ash concrete mixes was decreased as the level of coal bottom ash increased. This decreasing of slump values can be explained by the fact that water absorption of bottom ash was much higher than that of normal aggregates. So bottom ash affect flow characteristics of concrete mixture. Similar results are found by other investigators [18].

3.2. *Compressive Strength*

In order to verify the mechanical strengths at 28 days of the tested concrete, the cylindrical specimens (160* 320 mm) were made according to the composition indicated in the previous table 4 and table 5.

The specimens were stored for 24 h ± 1 h in a room kept at 20 ° C ± 2 ° C. After demolding, the specimens were kept at the same temperature, in a humid chamber (relative humidity greater than or equal to 95%). Then, the ends of the specimens were previously rectified by sulfur surface treatment. These specimens were subjected to the compressive test at the age of 28 days. Compressive tests were carried out on mechanical machine, Zwick 1494 type. This latter is controlled by a computer. The tests were conducted under standard temperature and humidity conditions (23 ° C - 50% RH).

In order to obtain a representative results of compressive strength, the tests were carried out twice for each measurement. Indeed, for each substitution rate, two specimens were made.
The results of compressive strength were presented in figure 5 and figure 6. The test was carried out obtain compressive strength of concrete at the age of 28 days.

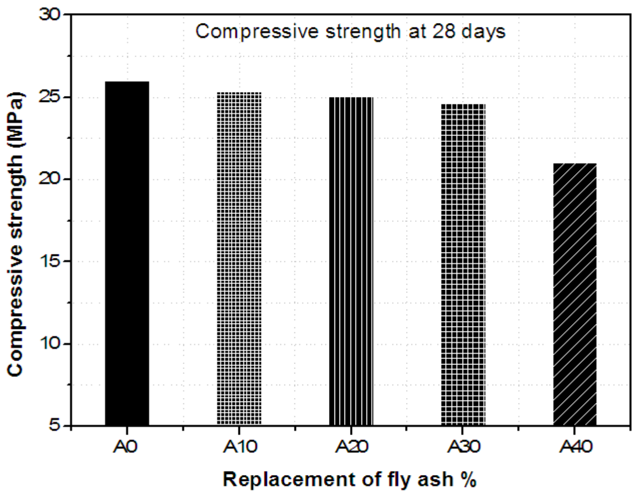

Figure 5: Effects of FA on compressive strength of concrete

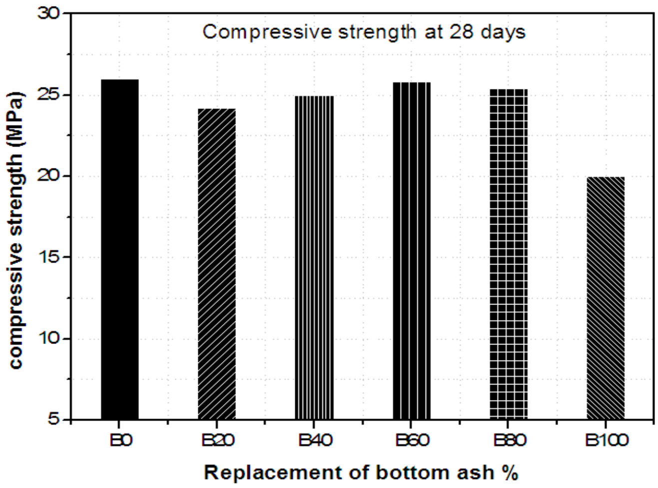

Figure 6: Effects of BA on compressive strength of concrete

From figure 5, it is seems that compressive strength did not affected by incorporating 10% ,20% and 30% of fly ash. This is due to the high pozzolanic nature of the fly ash and the fineness of the particles which improved the microstructure of the hardened concrete due to packing and filling effect. However up to 30% level of fly ash, Compressive Strength decrease. This result can be explained by the fact that high volume of fly ash cannot participate in the pozzolanic reaction just low volume can react while the other part remains unreacted even after a long period of curing [19]. Figure 6 shows the effects of bottom ash on the compressive strength at 28 days. The values of the compressive strengths were around 25 MPa and 26MPa when incorporating bottom ash 20%, 40%, 60% and 80% . So no significant effect by increasing the level of bottom ash in the concrete mixture until 80%. Except when bottom ash is used as total substitute of coarse aggregate, we observe a decreasing in compressive strength. This decreasing can be explained by the fact that normal aggregates are heavier than bottom ash.

Conclusion

In present investigation, different series of the experiments have been conducted on concrete with the addition of fly ash and bottom ash as partial replacement of cement and coarse aggregate, respectively. Based on the obtained results the following conclusion can be drawn.
1. The workability of fresh concrete A containing fly ash was decrease due to the higher water absorption of fly ash par comparing to the water absorption of cement. The same result is found on workability of fresh concrete B by incorporating bottom ash as partial or total replacement of normal coarse aggregate.
2. The compressive strength of concrete A containing fly ash did not affected because of the high pozzolanic nature of the fly ash. 30% of fly ash is considered to be the best ratio of cement replacement in a concrete mixture.
3. The use of bottom ash as replacement of coarse aggregate did not affect the compressive strength of concrete B but its incorporating as a total substitute has a negative impact. 80% of fly ash is considered to be the best ratio of coarse aggregate replacement in a concrete mixture.
4. Partially replacing cement with fly ash, the consumption of cement and CO_2 emission from the cement production reduces significantly.
5. Incorporating bottom ash as replacement of coarse aggregate has double benefits: solve the problem of their storage and conserve natural resources.
6. Future effort will be focused on the confirmation of these results by studying the compressive strength in long-term.

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