Characterization and evaluation of sudanese fly ash as partial replacement for cement in concrete mixes

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Abstract

The main objectives of this paperare to characterize the physical and chemical properties of the locally produced fly ash, to study its suitability to be utilized in concretemixes and to determine the degree of its pozzolanicity .Physical and chemical properties of fly ash were tested according to the standards of the American Society of Testing and Materials (ASTM C311-02). Fly ash was tested for density, fineness, moisture, Loss on Ignition (LOI), chemical composition, X-ray Fluorescence test (XRF), X-ray Diffraction test (XRD) and strength test. The results were then compared with the ASTM C618-03. It was found that the locally produced fly ash contains high level of silica, hence it can be classified, based on its chemical composition, as class F fly ash; this may be probably due to the addition of sand applied in the combustion chamber. The XRD showed that it contained crystalline form of silica which is not good for the use in concrete. On the other hand, the strength test proved that there was a degree of strength and pozzolanicity obtained. The strength activity index of 28-day was found 70%.This may be due to presence of amorphous silica within the crystalline one.

مستخلص

تهدف هذه الورقة العلمية بصورة أساسية إلى دراسة الخواص الكيميائية والفيزيائية للرماد المتطاير المنتج محلياً. كما تهدف إلى تحديد ما إذا كان الرماد المتطاير المنتج محلياً صالحاً للإستخدام في الخلطات الخرصانية ، وتحديدٍ درجة البوزولانية له. تمت دراسة الخواص الكيميائية والفيزيائية للرماد المتطاير وذلك وفقاً لمعايير الجمعية الأمريكية للإختبارات والمواد (ASTM C 311-02). تم إختبار الكثافة، درجة النعومة، الرطوبة، متبقي الإحتراق(LOI)، التركيب

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الكيميائي،وميض الأشعة السينية(XRF)،إنحراف الأشعة السينية (XRD)،بالإضافة لإختبارٍ المقاومة. وتمت مقارنة النتائج بمعايير ASTM C618-03. وجد أن الرماد المتطايرٍ المنتج محلياً يحتوي على نسبة عالية من ثاني أكيسد السيليكون(السيليكا)- والذي نتج غالباً من إضافة الرمل التي تتم في غرفة الإحتراق- وبالتالي تم تصنيفه على أنه من الدرجة F. كما كشف إختبار إنحراف الأشعة السينية (XRD)أنه يحتوي على سيليكا متبلورة الشئ الذي يجعل الرماد غير جيد للإستخدام في الخلطات الخرصانية. لكن وبالمقابل فقد تم الحصول على درجة لا بأس بها من المقاومة والبوزولانية عند إجراء إختبار المقاومة ، فقد كانت نتيجة معامل البوزولانية 70% عند 28 يوماً ، الشئ الذي قد يعزى إلى وجود بعض من السيليكا في صورة غير متبلورة . يعتبر هذا البحث بمثابة بداية وتمهيد للطريق ولا زالت هناك العديد من الجوانب يجب التطرق لها بالبحث. في هذه المرحلة من الضرورة بمكان دراسة خواص وظروف إحتراق الفحم البترولي وكيفية التحكم بها من أجل تحسين خواص الرماد المتطاير الناتج.

1. Introduction

The locally producedfly ash from Garri4 Sponge Coke-Fired Power Plant poses a real environmental problem because it is disposed-off in huge piles in the plant's vicinity.

Fly ash is defined as the finely divided residue resulting from the combustion of ground or powdered coal, which is transported from the firebox through the boiler by flue gases. Fly ash is a by-product of coal-fired electric generating plants[1]. One of the best indications of performance in the furnace is the quality of ash coming out of a power plant's boiler.Oxygen content,fuel particle size, amount and flow of makeup bed material (sand in case of Garri) and fuel to air distribution ratio should all be controlled [2]. Physically, fly ash is a very fine, powdery material; composed mostly of silica[3]. The major chemical constituents of most of the fly ashes are Silica (SiO_2), alumina(Al_2O_3), ferric oxide (Fe_2O_3) and calcium oxide (CaO)[4].

Fly ash is classified according to the American Society of Testing and Materials (ASTM) into two broad categories: class F fly ashes that have high silica content and low lime content and class C fly ashes that have high lime content[5].

Fly ash was originally used in concrete in the 1970s. The major reaction that takes place is between the reactive silica of the pozzolan and calcium hydroxide-generated from the hydration of cement- producing calcium silicate hydrate.Fly ash (class C and class F) added to concrete as a supplementary cementing material imparts one or more of the following benefits:

- Reduces the cement content.
- Reduces water required.
- Reduces heat of hydration.
- Improves workability of concrete.
- Attains higher levels of strength in concrete especially in the long term.
- Improves durability of concrete.
- Increases the "green" recycled material content of concrete.
- Attains a higher density.
- Lowers porosity and permeability.(6).

Hence the purpose of this paper was to study the potentiality and possibility of the Sudanese fly ash to be used as pozzolanic material in concrete mixes. It also aimed to determine the degree of pozzolanicity of Sudanese fly ash.

2. Materials and test methods

Physical and chemical analyses have been performed,particularly,X-Ray Fluorescence (XRF),X-Ray Diffraction (XRD) and strength tests. Moreover, the following tests have been performed:

2.1 Density:

The density was tested in accordance with the standard method (ASTM C311-02).

2.2 Fineness:

The sample was sieved through 75 µm (200) mesh and the retained amount was calculated as percentage of the total sample.

2.3 Moisture content:

The test was performed according to the American standard test method (ASTM C 311-02).

2.4 Loss on Ignition (LOI):

The test was performed according to the American standard test method (ASTM C 311-02)

2.5 Chemical composition:

The sample was analyzed to determine its chemical composition. The tests were performed according to the American standard test method ASTM C 311-64 T.

2.6 X-Ray diffraction (XRD):

The objective of the XRD test is to measure the crystal structure of fly ash. In this research a Philips PW 3040-60F, XbertTrocolsent was used. It was operated at voltage of 40 KV and current of 50 mA. The sample was scanned at 2θ range of 2-70° and at a speed of 0.05° 2θ/min and step size of 0.02 and time step of 0.5.

2.7 Strength activity index test:

Mortar cubes were casted after mixing fly ash with cement in order to determine the strength activity index of fly ash. Cement was replaced by fly ash with the percentages of 20%, 30% and 50%. Control sample (0% fly ash) was prepared for the purpose of comparison and for the calculation requirements. Mix design was performed according to the BS4550.The mortar samples were first mixed then they were molded in (40*40*40)mm^3 cubes. Then they were cured and crushed at different ages. The water to cement ratio was taken (w/c = 0.5).Table(1) below shows the mix design components.

Table (1): Quantities of components in mix design

Sample	Cement (g)	Water (ml)	Sand (g)	Fly ash(g)
Control	450	225	1350	0
20% replaced	360	225	1350	90
30% replaced	315	225	1350	135
50% replaced	225	225	1350	225

Strength activity index was determined in accordance with ASTM C 311-02 as follows:

Strength activity index= A/B *100

Where: A = Average compressive strength of test mix cubes B= Average compressive strength of control mix cubes

20% replacement sample at age of 28-day was used in this calculation according to ASTM C311-02.

3.Results

3.1 Results of physical analysis:

Table(2): Shows the physical analysis results of fly ash

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Property	Unit	Value	Target According to ASTM C618-03
Density	g/cm^3	1.185	-
Fineness	%retained on75μm sieve	34.57	-
Moisture Content	%	0.21	Max 3.0 %

3.2 Results of chemical Analyses:

Table (3) Shows the chemical analysis results of fly ash:

Table (3): Results of chemical analysis of fly ash

Property	Unit	Value	Target According to ASTM C618-03
Silicon Dioxide (SiO_2)	%	80.74	min of total 70 %
Aluminium oxide (Al_2O_3)	%	4.35	
Iron oxide (Fe_2O_3)	%	0.91	
Calcium oxide(CaO)	%	9.21	
LOI	%	4.5	Max 6.0 %

3.3 XRD Results interpretation:

The XRD results were interpreted with reference to the typical d- value for different crystals taking into account the results of the chemical analysis. It should be noticed that the results presented in Fig(1) are not correct since neither lead nor potassium was found in the chemical analysis of the sample. The X-Ray diffraction results showed about ten peaks. The most intensive one (100% intensity) has a d value of 3.2°A(Angstrom) which is the d value of quartz. There were other four small peaks of quartz at (4.2, 1.8, 1.52 and 1.66) °A. There was one peak of crystobalite at 2.4°A. There was also a small peak of calcite at 1.9°A, a small peak of sodium feldspar at 2.05°A and a small peak of kainite at 1.4°A.

There are three polymorphs of silicon dioxide; quartz, crystobalite and tridymite. Among them quartz is the most strong one and has a higher index of refraction. XRD results showed about five peaks of quartz and one peak of crystobalite; this is may be due to the high level of silica (80%) revealed in the chemical analysis.

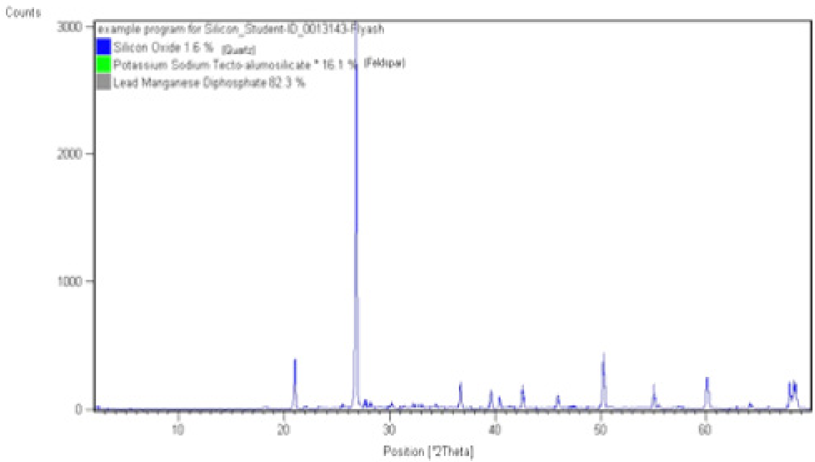


Fig (1): XRD Test Results

3.4 Strength activity test:

Strength Activity Index Calculations:

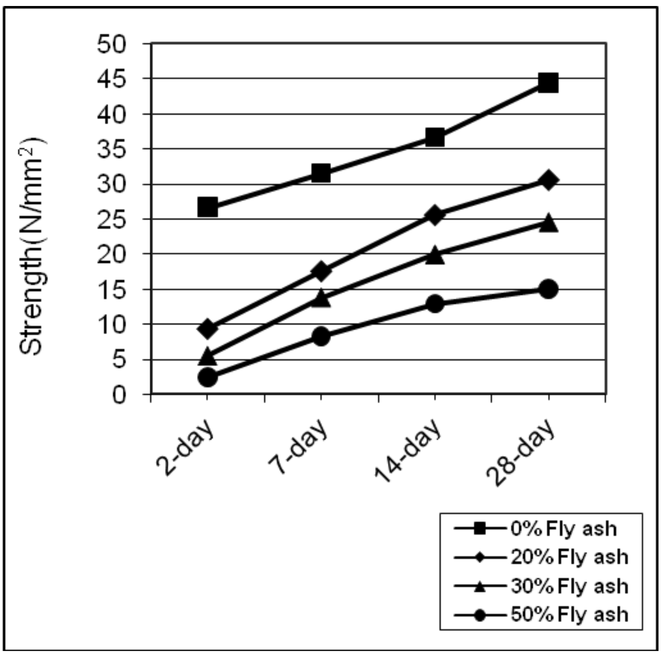
Strength Activity Index % = (strength of 20% replacement at 28-day/strength of control sample at 28-day) *100
Strength Activity Index of 28-day = (31/44)*100 = 70%

Table (4) below shows the strength obtained with different replacement percentages and at different ages.

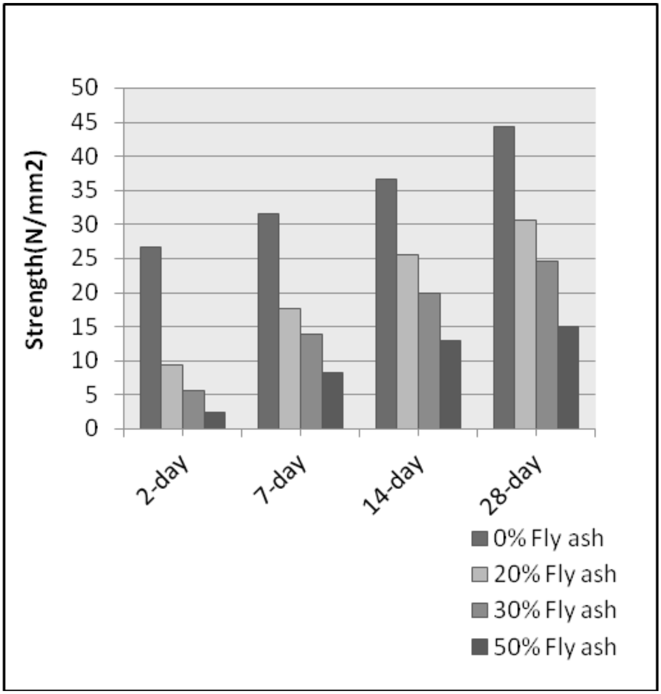
Table(4): Strength at different replacement percentages and at different ages

	0 % Fly ash	20% Fly ash	30% Fly ash	50% Fly ash
Strength at 2-day (N/mm^2)	26.6	9.4	5.6	2.5
Strength at 7-day(N/mm^2)	31.5	17.6	13.9	8.3
Strength at 14-day(N/mm^2)	36.6	25.6	20.0	12.9
Strength at 28-day(N/mm^2)	44.4	30.6	24.6	15.0

The two graphs below show the strength obtained from the control sample and the fly ash replacement samples with different percentages at different ages.



Fig(2): Comparison between strength of different fly ash replacement percentages along with time



Fig(3): Histogram of strength of different fly ash replacement percentages along with time

4. Discussion of results

4.1 Physical analysis results:

ASTM C 618-03 states that the fineness of the fly ash shall be less than 34% retained on the 45 µm-sieve. Fineness of the sample was determined usig 75 µm sieve (the smallest available sieve in Sudan). The result for 75 µm was 34.75 % retained, so it would definitely be less than that for 45 µm and hence the fineness of the local fly ash is acceptable.

According to the ASTM C 618-03 there is no requirement for fly ash density. The density was compared with the study conducted by XiupingFeng and Boyd Clark; they had tested forty nine ash products from different sources in the USA. The densities of the fly ashes are distributed between 1.75 to 2.88 g/ cm^3[7]. It was observed that the density of the local fly ash was below this range but the density of fly ash clearly differs from one source to another.

4.2 Chemical composition:

The results were compared with the standard method ASTM C 618-03. This fly ash contains large amount of silica (SiO_2) and small amount of lime (CaO), hence it can be classified as class F.ASTM C 618requires that the sum of the (SiO +Al_2O_3 + Fe_2O_3) shall not be less than 70 %. The result was 86 % which conforms with the standard. It was observed that the sample contains large amount of silica (SiO_2), namely 80.74 % which was higher than the typical ranges of silica in class F fly ash (40 to 60)%. The combustion conditions were investigated and an addition of silica in the form of sand has been found in an uncontrolled manner, which may result in high content of silicon dioxide in fly ash.

4.3 Strength activity index:

ASTM C618-03 specifies 75% as minimum of strength activity index, but the local fly ash has lower strength activity index than the minimum required. On the other hand it is not a negligible, actually it is a considerable gain in strength and the reason behind this low pozzolanicity index is due to the presence of crystalline silica proved by the results of XRD test.

4.4 XRD Test results:

Presence of crystalline silica, which has been proved by the XRD, indicates low activity index of the fly ash. Because crystalline silica is the non-reactive form of silica and cannot react with the lime produced during the hydration process, hence it does not contribute to the developmentofstrength. On the other hand the strength activity test showed that there is some gain of strength. The strength activity index was 70%

and which is just below the minimum target,as said before.

5. Conclusions

According to the physical and chemical analysis for locally produced fly ash, it was found that:

- It has good chemical and physical qualities when compared with the standards. It was observed that there was high content of silica which could have been good if it was amorphous, but the XRD test proved that it was crystalline.

- The strength test results showed that the locally produced fly ash from Garri4 Sponge coke-fired Power Plant is a relatively weak pozzolan and its strength activity index is 70% which is slightly below the minimum target of 75% set by the American Society for Testing and Materials ASTM C 618-03. Hence it does not improve the strength of concrete

- The combustion conditions were investigated in order to find out the reason behind the existence of crystalline silica in fly ash .Accordingly, it was found that the control of combustion conditions was weak and the amount and flow of sponge coke and air are not controlled. It was also found that the problem of crystalline silica was traced back to the addition of uncontrolled amount of sand in the combustion chamber.From historic records it was found that there is a problem of inconsistency in the properties of Garri4 fly ash; this is probably due to the poor combustion control. Changeability in fly ash properties will hinder any future utilization endeavors.

6. Recommendations

Based on the results obtained and the conclusions drawn from this study, it is recommended to follow the points below in order to improve the properties of locally produced fly ash:

- To study the utilization of locally produced fly ash in other constructional applicationssuchas bricks, light weight aggregate and asphalt concrete.

- To apply a quenching process of fly ash in order to minimize crystal formation of silica.
- To control the combustion characteristics of Garri 4 in order to improve its fly ash properties.

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