International Journal of ChemTech Research
CODEN (USA): IJCRGG ISSN: 0974-4290
Vol.8, No.3, pp 1019-1025, 2015

Use of Pulverised Fuel Ash in the Manufacture of Concrete Roofing Tiles

Pardon K. Kuipa[1,2,*], Cledwyn T. Mangunda[1], Olga Kuipa[1], and Admire Chawatama[1]

[1]Department of Chemical Engineering, National University of Science and Technology, Bulawayo, Zimbabwe
[2]School of Engineering Sciences and Technology, Chinhoyi University of Technology, Chinhoyi, Zimbabwe

Abstract: We have investigated the use of Pulverized Fuel Ash(PFA), commonly known as "fly ash", for the manufacture of concrete roofing tiles. A portion of the cement used in the process was substituted with PFA thereby reducing raw material costs. Strength development, water absorption, and concrete water demand of the PFA-Cement tile were analysed. Results showed the possibility of substituting 20% of cement by PFA. This increased the overall tile strength by an average of 6.5% and reduces the process water demand by 7.5%. The use of 20% PFA reduces the theoretical carbon dioxide emissions of the tile manufacturing process. The tile quality improved as PFA reduced concrete tile efflorescence and bleeding.

Introduction

Pulverized Fuel Ash (PFA) is a by-product of the combustion of pulverized coal in power generation plants and also in coal fired steam boilers. When coal is combusted, carbon and the volatile materials are burnt off but however some mineral impurities of clay, shale, feldspars are fused in suspension and carried out of the combustion chamber as pulverised fuel ash in the exhaust gases. PFA is a pozzolan and can replace cement in concrete works.

PFA concrete exhibits increased densities and long term pozzolanic action of fly ash, which ties up free lime, resulting in fewer bleed channels and decreases permeability. Free lime and other salts are capable of creating efflorescence (the formation of white salt deposits due to the reaction of $Ca(OH)_2$ with water and CO_2 on the surface of concrete causing discolouration of the concrete) such that by the inclusion of PFA in the concrete mix efflorescence can be hindered[1].

Incorporating PVA in a concrete mix design also enables cement and concrete producers to reduce greenhouse gas emissions associated with the manufacture of Portland cement and concrete. It reduces the green gas "footprint" of concrete, as the production of one ton of Portland cement produces approximately one ton of CO_2 as compared to zero CO_2 being produced using fly ash[2]. As fly ash use in concrete increases, it leads to greater environmental sustainability through both avoidance of landfill and the reduction of natural resource consumption, saving resources for the future.

Physical and chemical properties of PFA

Physical properties of PFA

Fly ash consists of fine, powdery particles that are predominantly spherical in shape, either solid or hollow, and mostly glassy (amorphous) in nature. The carbonaceous material in fly ash is composed of angular particles. The particle size distribution of most bituminous coal fly ashes is generally similar to that of silt (less than a 0.075mm). Although sub-bituminous coal fly ashes are also silt-sized, they are generally slightly coarser than bituminous coal fly ashes[3].

The specific gravity of fly ash[4] usually ranges from 2.1 to 3.0, while its specific surface area may range from 170 to 1000 m^2/kg. The color of fly ash can vary from tan to gray to black. This depends on the amount of unburned carbon in the PFA, with the lighter shades of gray generally indicating a higher quality of ash (less unburned carbon).

Chemical properties of PFA

Fly ash is a heterogeneous material. SiO_2, Al_2O_3, Fe_2O_3 and occasionally CaO are the main chemical components present in fly ashes. The mineralogy of PFA varies with the type of coal. The main phases encountered are a glass phase, together with quartz, mullite and the iron oxides. The other phases often identified are cristobalite, anhydrite, free lime, calcite, halite, portlandite, rutile and anatase[5]. There are two types of fly ash; class F and class C. Class F fly ash is designated in[6] ASTM C618-12a and originates from anthracite and bituminous coals. It consists mainly of alumina and silica and has a higher LOI than Class C fly ash. Class F fly ash also has a lower calcium oxide content than Class C fly ash. Both types of fly ash undergo pozzolanic reaction with free lime to produce the same cementitious compounds formed by the hydration of Portland cement. Class C fly ashes may possess enough CaO to be self cementing in addition to the pozzolanic reaction with free lime during cement hydration.

The use of PFA leads to higher ultimate strength, increased workability, reduced bleeding, reduced permeability, reduced water demand and reduced thermal cracking[2,7,8,9,10].

Experimental

Cement and PFA specific surface area and setting time.

The specific surface area (SSA) of the cement and PFA is determined using the Blaine's air permeability test. The setting time of different compositions of PFA is to be measured using the Vicat apparatus. The following is the procedure for testing the setting time of PFA/cement,

1. Make a PFA/Cement composite sample by weighing the individual samples to come up with required proportion. This should total 200+/- 0.10g.
2. Measure 52 +/- 1 ml of clean water using a graduated measuring cylinder.
3. Using ganging trowels, mix thoroughly the PFA/Cement test specimen and the pre-measured water to form a cuboid with the paste ensuring that it is flat at the top.
4. Test for initial and final setting time of the prepared cuboid using the Vicat apparatus.

Tile manufacture.

Concrete tiles were manufactured by part substitutions of cement by PFA. All the other raw materials (sand and pigment) were kept constant in the concrete mixture. Standard mixing, forming and drying conditions were maintained.

Determination of the effect of PFA on the water demand of the concrete mix.

The amount of water required for workability of concrete differs with the amount of PFA present. The water demand was measured as follows,

1. Mix the PFA, cement, sand and pigment in the rotary mixer without water.
2. Add 75% of the theoretical water requirement of the concrete mix.
3. Add water gradually visually checking the workability of the concrete mix and stop adding the water when acceptable workability is achieved and record the amount of water added.

Strength development of the manufactured concrete tiles.

Concrete tiles produced were tested for strength development. This was done by monitoring the compressive strength of the tiles after 24 hours, 7 days, 14 days, and 28 days. The following procedure was used to determine the compressive strength of the concrete tiles,

1. Immerse the concrete tiles in a water bath at room temperature for 24 hours.
2. Remove the tiles and let them drip of the water for 30minutes at room temperature.
3. Place the tile under the Testometric tester and lower the breaker slowly by increasing the pressure gradually.
4. Note the pressure at which the tile breaks.

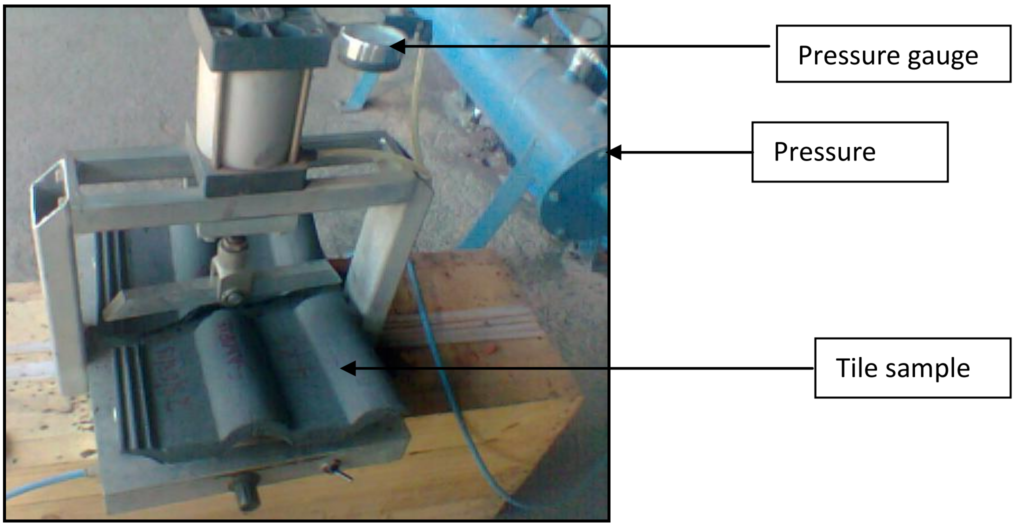

Figure 1. Experimental setup for testing the compression strength of concrete tiles.

Determination of the effect of PFA on water absorption

The water absorption of a concrete tile is tested as follows,

1. Weigh a dry concrete tile and record the mass.
2. Immense the dry concrete tile in water at room temperature for 24hours.
3. Remove the tile and leave for about 30 minutes for water to drip off and then weigh it on a scale.
4. $$Absoption = \frac{final\ weight - \ initial\ weight}{initial\ weight}\ x\ 100\%$$

Effect of water permeability

Concrete tiles produced are to be tested for water permeability. Permeability of concrete generally refers to the rate at which water can penetrate the concrete. The following procedure was used,

1. Place a walled frame on the tile and seal the entire perimeter of the tile in the frame and nail holes using a sealant e.g. putty or mastic to provide a water tight seal.

2. Add water to a depth of 50+/- 5mm into the wall frame measured from the highest point of the upper surface of the tile.

3. Leave the tile for 24 hours and then check for signs of water droplets on the underside of the tile.

Determination of the effect of PFA on concrete tile bleeding.

Concrete tile bleeding in the tiles manufactured using PFA was monitored 24 hours after the manufacture of the tiles. This was done by checking for any white marks on the tiles.

Results and Discussions.

Cement and PFA chemical composition.

The PFA used in the experiments had the following chemical composition.

Table 1. Chemical composition of PFA.

Component	Percentage constitution (%).
Sio$_2$	41.3
Al_2O_3	33.0
CaO	4.8
MgO	0.8
Fe_2O_3	14.8
Ti_2O	1.3
Sio$_2$ + Al_2O_3 + Fe_2O_3	89.1

The PFA contains SiO_2, Al_2O_3 and Fe_2O_3 which has a sum of 89.1% and CaO which is less than 15% (Table 1) which then classifies this type of PFA as type F according to the American Society for Testing and Materials[6].

Cement and PFA specific surface area (SSA).

Table 2. Cement and PFA specific surface area.

	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5
Cement(kg/m^2)	319	318	319	320	320
PFA (kg/m^2)	346	345	345	347	345

The specific surface area of cement was found to be 319kg/m^2 on average and that of PFA was 345 Kg/m^3 on average (Table 2). The requirements[11] for the SSA of cement is between 280 – 320kg/m^2 and that of PFA to be used in concrete is specified[6] to be greater than 250 kg/m^2. This then shows that the cement and PFA used conform to these requirements.

Effect of PFA on concrete tile setting time.

The results for the initial and final setting times for the different blends of concrete is shown in the graph below.

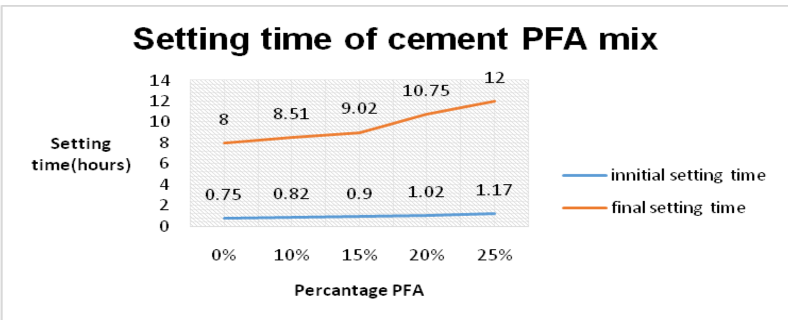

Figure 2. Effect of PFA on the setting time of cement.

Figure 2 shows the initial and final setting time of the different blends of cement and PFA. From Figure 2, the initial and final setting time increased with addition of PFA. The initial setting time increased with increase in PFA addition due to the reduced hydration reactions caused by the increasingly low CaO in the mixture. The acceptable[12] initial setting time is 45-60 minutes making substitution of 25% PFA not suitable due to its high initial setting time of 69.6 minutes.

The acceptable[12] range of final setting is 10 hours to 12 hours. PFA substitution from 10% to 25% does not affect the final setting time of the concrete tile as it falls within the range.

Effect of PFA on the concrete mix water demand.

The percentage water reduction is shown below.

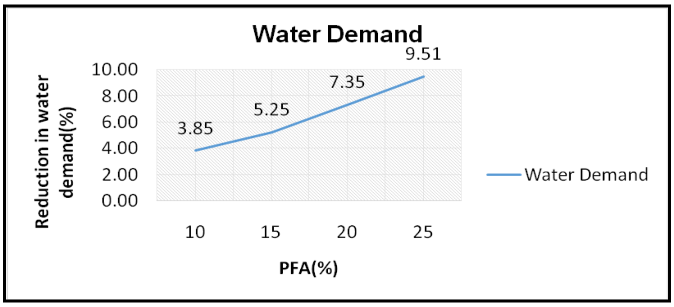

Figure 3. Effect of PFA on concrete mix water demand.

Figure 3 shows the reduction in water usage that was observed during the manufacture of concrete tiles using different blends of cement and PFA. An average of 3.85% in water demand was recorded at 10% PFA, and 5.25% water reduction at 15% PFA. Maximum water reduction was 9.51% for 25% PFA. It can be noted from Figure 3 that the water usage for manufacture concrete tiles containing PFA varies between 3 – 4% for every 10% PFA added. The decrease in water requirement is attributed to the ball-bearing effect of spherical particles of PFA. As a consequence of the spherical shape of the fly ash, finer particles of the ash become adsorbed on the surface of the cement particles so that when they cover the whole surface of the cement particles the water demand for the paste/mortar decreases[13]. Helmuth[7] based on analysis of data from a large number of studies, reported that water reduction is a result of adsorption of the fine fly ash particles on cement particles which in turn causes dispersion of cement particles in a manner identical to that of organic water reducing admixtures.

Strength development of the PFA-Cement tiles.

The following are the results for the strength development of concrete tiles noted over a period of 90 days. 3 tiles were tested per run for each of the different cement/PFA blends used thus bringing the number of tiles tested to 45 for the each of the different testing days.

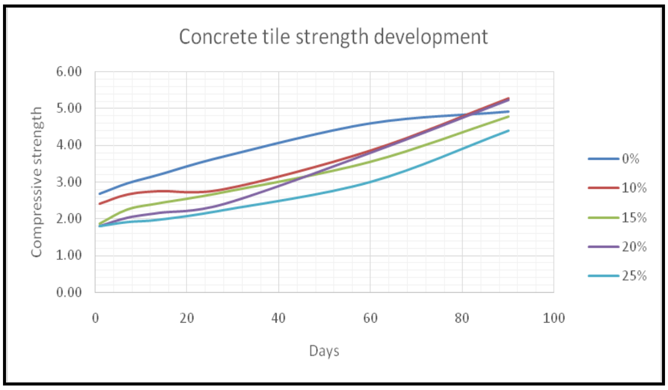

Figure 4. PFA concrete tile strength development.

Figure 4 shows the strength development of concrete tiles over a period of 90 days. There was low strength development of concrete tiles containing PFA during the first 28 days. In this period hydration reactions of cement are predominant and are the major contributors of strength development. After 28 days the rate of strength development increases due to the additional pozzolanic reactions between the PFA and the hydration reaction products. 10% and 20% PFA concrete tiles exhibited a relatively higher strength development reaching a maximum of 5.28 bars and 5.22 bars respectively in which both values are higher than for tiles with only cement which had an average compressive strength of 4.91 bars. From Figure 4 concrete tiles with 25% PFA exhibited the lowest strength development and the minimum 90 day compressive strength of 4.4

bars. This is due to the lower amount of cement in the blend hence the lesser amount of free lime present for pozzolanic reaction with the PFA.

The required[11] strength is for concrete tiles is 3.1bar shown in Figure 4. Tiles with 10% PFA attained this at 28 days and those with 15% and 20% attained the required strength at 38 and 36 days. Tiles with 25% PFA attained this latest with 55days.

Effect of PFA on tile weight.

Concrete tiles produced using different blends of cement and PFA were measured and the following results were found.

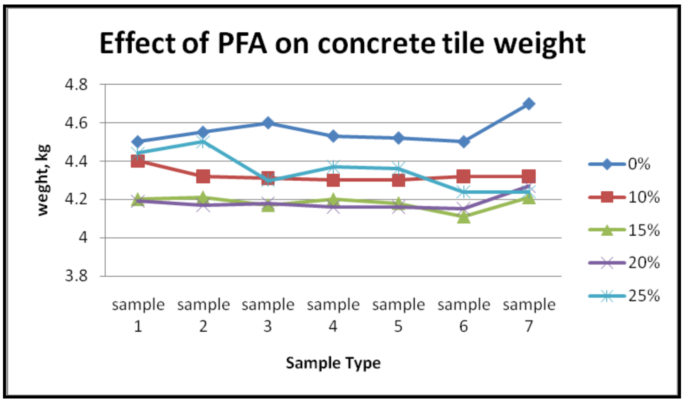

Figure 5 Effect of PFA on concrete tile weight.

The weight of concrete tiles measured was seen to decrease with addition in the amount of PFA (Figure 5). There was a reduction of 4% in weight for tiles with 10% PFA compared to the conventional tiles with an average weight of 4.32kg compared to 4.53kg for 0%PFA tiles. A decrease of 7.28% was noted for tiles with 15% PFA and 7.95% for tiles with 20% PFA which recorded the lowest average weight of 4.17kg. Concrete tiles with 25% PFA only recorded a decrease in weight of 2.9% due the packing effect caused by the increased number of PFA fine particles.

Effect of PFA on concrete tile permeability.

Concrete tiles produced were tested for water permeability and all the blends of cement and PFA passed the test. No water droplets or marks were found on the underneath of the tile after a period of 24 hours of the tiles holding the water.

Effect of PFA on concrete tile water absorption.

The following are the results obtained for the water absorption of concrete tiles which contained different blends of PFA and cement.

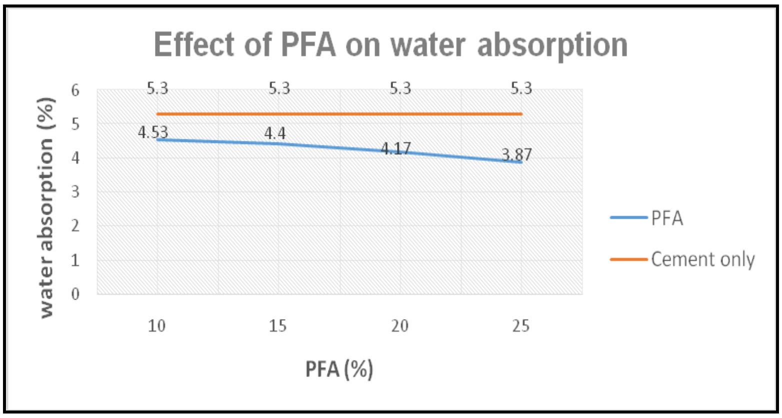

Figure 6. Water absorption of concrete tiles.

Figure 6 shows the water absorption of tiles. Tiles without PFA have the highest absorption value of 5.3% with those containing 10% PFA having an average of 4.53%. The water absorption of concrete tiles decrease with increase in PFA added with tiles containing 25% PFA having an average water absorption of 3.87%. The reduction in water absorption for tiles containing PFA is attributed to the packing effect due to the fine PFA particles and sealing of pores by pozzolanic reaction products. Formation of pozzolanic products such as calcium silicate hydrate causes the filling of pores present in the hardened mass resulting in a much denser concrete thus preventing absorption of water or gases into the concrete.

Conclusion

Class F type of PFA was used in the experiments. An increase in the amount of PFA increases the setting time of the cement/PFA blend. The presence of PFA in the concrete mix reduces the water demand of the mix thereby reducing the water usage. The strength development of tiles with PFA surpasses that of tiles without PFA from 28 days up to 90 days resulting in PFA containing tiles having a relatively higher strength. Permeability, efflorescence and bleeding were minimised by the use of PFA in concrete tiles. From these experiments 20% PFA is recommended for substitution of cement in tiles due to the resultant high strength tiles. However this would increase the curing time by 8 days though no additional costs would be incurred.

References

1. Najafi Kani. E, Allahvedi, A., Provis, J.L., Efflorescence control in geopolymer binders based on natural pozzolan, Cement and Concrete Composites, 34(1), pp.25 -33, 2012.
2. Islam, M. and Islam, S., Strength behavior of mortar using fly ash as partial replacement of cement, Concrete Research Letters, 1(3), pp.98-106, 2010.
3. Joshi, R.C. and Lohtia, R. P., “Fly Ash in Concrete Production, Properties and Uses”, Gordon and Breach Science Publishers, Amsterdam, pp. 1-47, 1997.
4. ASTM C204-11e1, Standard Test Methods for Fineness of Hydraulic Cement by Air-Permeability Apparatus, ASTM International, West Conshohocken, PA, 2011, www.astm.org
5. Snellings, R., Mertens, G., Elsen, J., Supplementary Cementitious Materials, Reviews in Mineralogy and Geochemistry, 74, pp. 211–278, 2012.
6. ASTM C618-12a, Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete, ASTM International, West Conshohocken, PA, 2012, www.astm.org
7. Helmuth, R.A., Water-reducing properties of fly ash in cement pastes, mortars and concretes: Causes and Test Methods, Proceedings of the Second International Conference on the use of Fly Ash, Silica Fume, Slag and Natural Pozzolans in Concrete, Madrid, Spain, V.M. Malhotra (editor), ACI SP-91, pp.773-740, 1986.
8. Krishnaraj, L., Ravichandiran, P.T., Annadurai, R., Kannan Rajkumar, P.R., Study on micro structural behavior and strength characteristics of ultra fine fly ash as a secondary cementitious material with Portland cement, International Journal of ChemTech Research, 7(2), pp. 555-563, 2015.
9. Sumathi, A., Saravana Raja Mohan, K., Compressive strength of fly ash brick with addition of lime, gypsum and quarry dust, International Journal of ChemTech Research, 7(1), pp. 28-36, 2015.
10. Rai, B., Kumar, S., Satish, K., Effect of fly ash on mortar mixes with quarry dust as fine aggregate, Advances in materials Science and Engineering, Volume 2014, Article ID 626425, 7 pages, 2014.
11. Standards Association of Zimbabwe (SAZ), Quality standards for cement manufacture, 4 November 2013.
12. Turnal Fibre Cement (TFC), *Quality manual.* Harare: Turnall Fibre Cement, Zimbabwe, 2012.
13. Abubakar, A.U., Baharudin, K.S., Properties of concrete using Tanjung Bin Power Plant coal bottom ash and fly ash, International Journal of Sustainable Construction Engineering and Technology , 3(2), pp. 56-69, 2012.

***** *****