EVALUATION OF POZZOLANIC ACTIVITY OF SOME CLAYS IN GHANA

Z. G. Momade
Department of Chemical Engineering,
Kwame Nkrumah University of Science and Technology, Kumasi

E. Atiemo
Building and Road Research Institute, University P.O. Box 40, Kumasi

ABSTRACT
A study of pozzolanic activity of four Ghanaian clays is presented. The moisture content, particle size distribution, and the chemical composition of clays were determined. X-ray diffractometric and thermal analysis were also performed to determine the mineralogical composition. Calcinations of the clays were carried out at different temperatures between 600-1000°C and the pozzolanas produced used to replace 20% Portland cement by mass in mortars. Compressive strengths of 1:3 pozzolana cement mortar cubes at 28 days were determined. The values obtained showed that Aşokwa (AS) and Mankesim (MN) clay samples become highly pozzolanic at 800°C whilst Hwereso (HW) and Nkonsia (NK) clays had their optimum calcination at 900°C and 600°C respectively. The compressive strengths were higher than the 24.1 N/mm² minimum standard set for concrete and general construction.

INTRODUCTION

Pozzolanas are siliceous and aluminous substances, which, in their finely divided form, react with lime in the presence of water at ordinary temperature to produce cementitious materials (Lea, 1970). They occur in natural and artificial form. Examples of natural pozzolanas are Italian natural pozzolana, tuff, trass, pumicite, santorin earth, and diatomaceous earth, whilst artificial pozzolanas are clay, shale, fly ash, bauxite waste, and blast furnace slag. Artificial pozzolanas have to undergo heat treatment before they become pozzolanic (Lea, 1970; Hammond, 1987; Wild, 1996; Wild at al., 1997).

Pozzolanas are used to replace Portland cement up to 40% in concrete and masonry works for housing construction (Lea, 1970; Malhotra, 1992, Wild, 1996; Wild at al., 1997). They are sometimes preferably used for construction because of their resistance to alkali-aggregate reaction, improved urability due to resistance to sulphate attack, improved workability, and lower cost among others. In some cases the use of pozzolana reduces environmental pollution since it makes use of the above-mentioned waste materials. Studies have shown that pozzolana cement produces strengths required for concretes and mortars (Hammond, 1987; Malhotra, 1992; Wild at al., 1997).

This paper presents a study of the pozzolanic activity of four selected clay deposits in Ghana. The chemical and mineralogical composition of the clays is determined to ascertain their suitability for pozzolana production. The optimum calcination temperature is established for the clays by evaluating the setting time and compressive strength of the calcined clay pozzolanas. The pozzolanas are compared to Portland cement.

Pozzolanic activity

Pozzolanic activity of clays depends on their clay minerals, which in turn determine their chemical compositions. Clay minerals are tiny crystalline hydrous aluminium silicates with particle size below 2μm incorporating other metallic ions and some impurities. They are evolved primarily from the chemical weathering of feldspars and micas. These crystalline minerals are stable, non-reactive and thus non-pozzolanic (Lea, 1970).

The pozzolanity of clays are developed during calcination between 500 – 900°C by the disruption of the crystalline structure and then grinding them to cement fineness (<75μm). Generally, the active components are either semi-amorphous siliceous and aluminous compounds with a highly distorted crystal structure (e.g. metakaolinite) or amorphous glassy phase. These compounds are very unstable and chemically active.

Clays differ in their chemical and mineralogical composition so they have different optimum temperatures at which calcining them gives the highest pozzolanic activity. There are many methods of determining the pozzolanity of materials. These include deductions based on chemical or mineralogical composition, determination of lime reactivity of pozzolana or compressive strengths of pozzolana cement (ASTM, 1979).

Lime reactivity test is an accelerated curing test in which the mortar test cubes are cured in a humid environment at 55°C for 7 days. This test allows quite a fast assessment of the activity of the pozzolana, but because of the test conditions, conclusions cannot be made about how strong the building material is going to be during construction works. The compressive strength test method cures the mortar cubes at ambient temperature for 28 days. Although the test requires longer time, the results are more reliable to evaluate how suitable the pozzolana is for construction purposes. Therefore the compressive strength test is mostly used to evaluate the pozzolanic activity (pozzolanity) of materials for construction purposes and this is the method adopted for the study.

MATERIALS AND METHODS

Materials

The four clay samples selected for the study were Asokwa (AS) and Hwereso (HW) clays in the Ashanti Region, Mankesim (MN) clay in the Central Region and Nkonsia (NK) clay in the Brong-Ahafo Region. Other materials used were ordinary Portland cement, produced in accordance with BS 12 standards (BSI, 1992), and sand. The sand was prepared such that all passed through a standard 0.8-mm sieve but not more than 10 % passed through a 0.6-mm sieve.

Asokwa clay is derived from the weathering of Lower Birimian (Middle Precambrian) Phyllites. Hwereso clay is a red loamy one and is a deeply weathered soil over igneous or metamorphic rocks found in the humid zone of Ghana. Mankesim clay is derived from the completed weathered Lower Birimian Schists while Nkonsia clay is the residual product of the weathering of arkoses, siltstone and shale in sandstone (Frempong and Atiemo, 1992).

The physical properties of the clays and cement were determined according to BS 1377 (BSI, 1990), and shown in Table1. From the particle size distribution the clay, silt and sand contents were also calculated. The chemical composition of the clay samples and cement was determined by gravimetric methods according to ASTM standards (ASTM, 1979) and also presented in Table 1.

All four clay samples had high silica content between 60-70%, an appreciable amount of Al_2O_3 (15-18%), and 4.5-9% of Fe_2O_3, the red samples having the higher values.

The mineralogical compositions were analysed by X-ray diffractometry (XRD) using a Philips PW 1710 diffractometer with copper anode and 40 kV generator voltage. The peaks on the diffractogram were identified using ASTM identification cards and the powder diffraction file (PDF) database of JCPDS-ICDD (1995) software.

Figures 1-4 show the X-ray diffractograms of the clay samples. The main peaks have been marked as shown. The major components of all the samples are kaolinite and quartz. Apart from these, each sample contained a small amount of chlorite. The red colour of Hwereso and Nkonsia clays is due to the presence of some goethite and hematite. Mankesim clay showed a few weak reflections associated with muscovite, illite and feldspar.

Table 1. Physical and chemical properties of clay samples and cement

Material	AS	HW	MN	NK	Cement
Colour	Yellow	Brownish red	Yellow	Brownish red	Grey
Moisture content, %	18.6	17.4	20.3	16.5	-
Specific gravity	2.65	2.72	2.71	2.69	3.05
Clay, %	43	33	32	37	-
Silt, %	43	27	30	16	-
Sand, %	14	40	38	47	-
SiO_2, %	69.8	60.3	67.6	68.5	19.6
Al_2O_3, %	15.7	18.2	16.3	16.5	6.5
Fe_2O_3, %	4.6	9.1	4.4	6.2	2.6
CaO, %	0.2	1.2	0.7	0.9	65.1
MgO, %	0.1	trace	0.1	0.2	2.5
SO_3, %	0.02	0.1	0.004	0.02	2.1
LOI, %	5.3	4.5	4.8	5.1	5.6
Kaolinite content, %	38	36	38	39.5	-

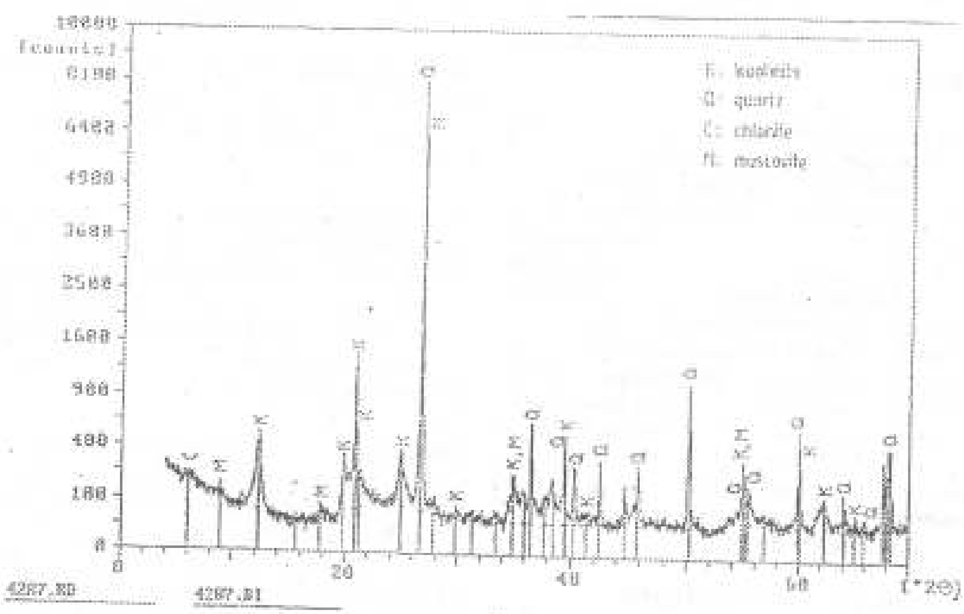

Fig. 1: X-rax diffractogram of Asokwa clay

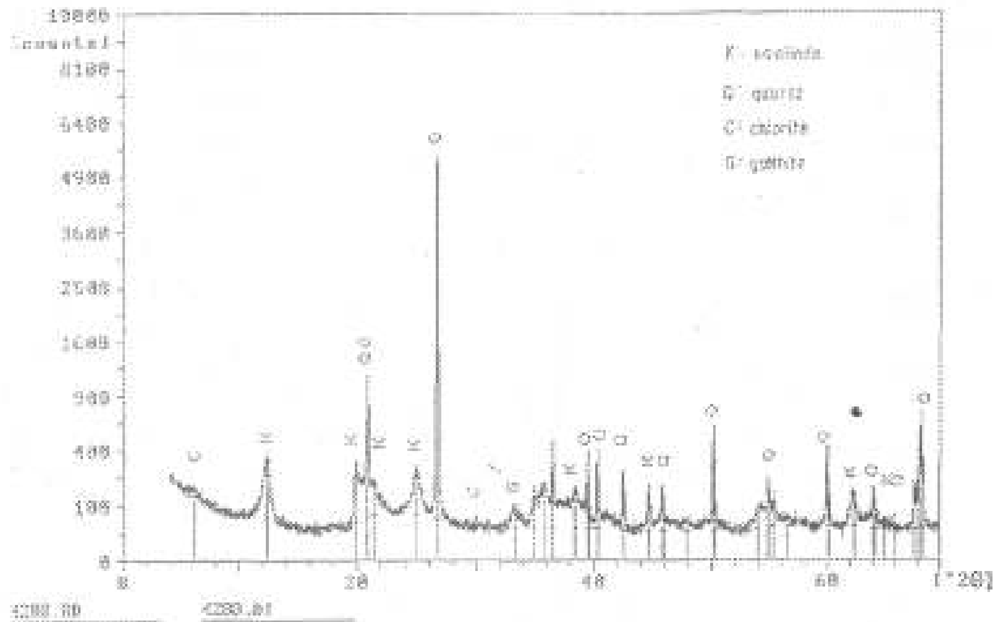

Fig. 2: x-ray diffractogram of Hwesreso clay

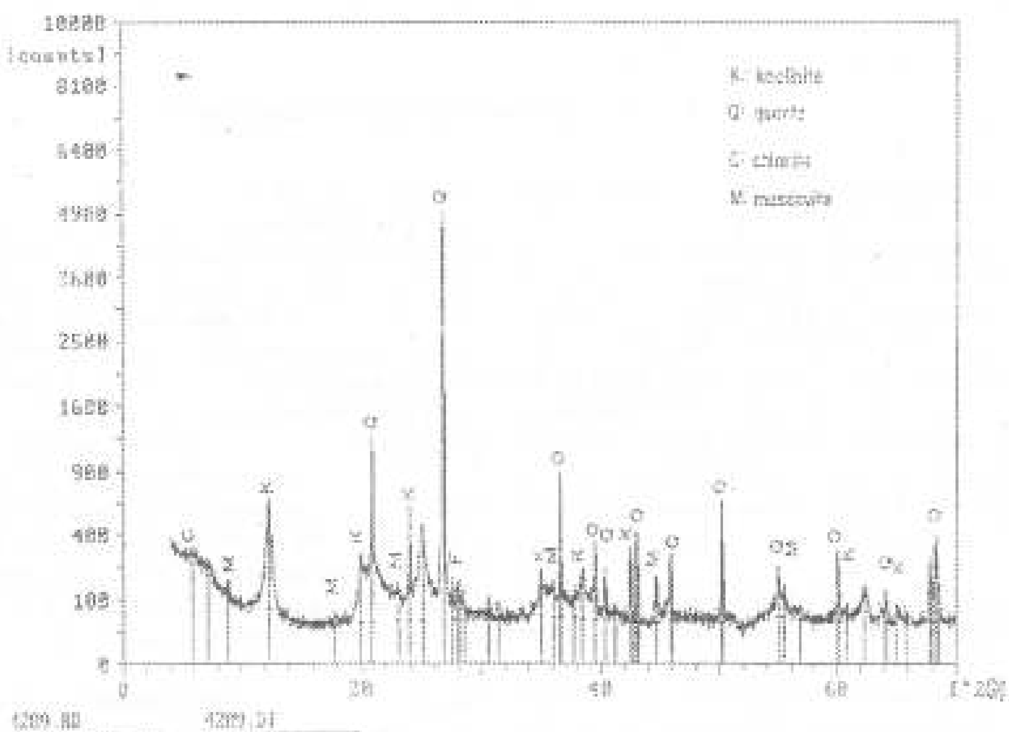

Fig. 3: X-rax diffractogram of Mankesim clay

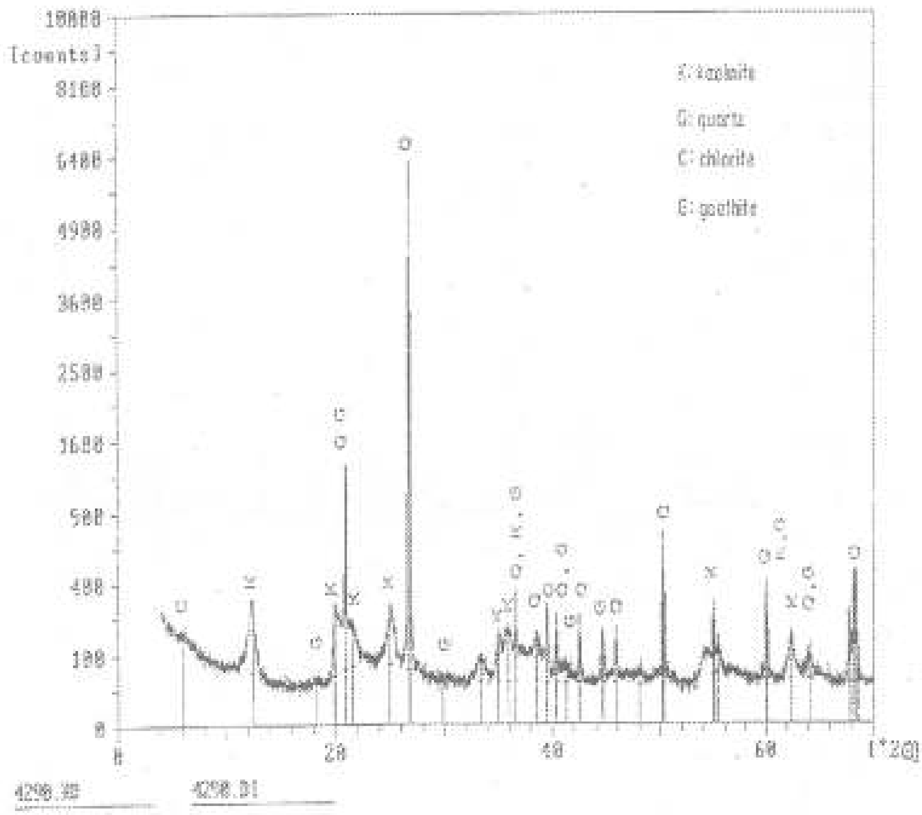

Fig. 4: X-ray diffractogram of Nkonsia clay

Thermal analysis was also carried out on the samples with a MOM Derivatograph. The instrument records the temperature (T), the thermogravimetric curve (**TG**), the differential thermogravimetric (**DTG**) and thermal analysis curves (**DTA**) simultaneously. The position of the various endothermic and exothermic peaks on the DTA curve serves as a means of qualitative identification on the substance. The measurements of mass losses associated with dehydration or decomposition provide a quantitative assessment of the compounds present.

Figures 5-8 present the thermal analysis curves for the clay samples. The samples gave very similar recordings, the difference being the total mass loss during the analysis and the mass loss associated with the decomposition of kaolinite. The thermal analysis shows mass losses in the 100-300°C temperature interval on the TG and DTG curves and corresponding endothermic peaks on the DTA curves for all four samples. This is associated with the expulsion of free and adsorbed water and around 290°C probably from the dehydration of goethite. The endothermic DTA peaks at 540-550°C show the expulsion of structural water principally from the crystal lattice of kaolinite. However, it must be noted that illite and muscovite also lose water at this temperature range. The mass loss on the TG curve corresponding to this change is a more reliable way to determine the kaolinite content of clay samples. The exothermic DTA peaks at 900-930°C show the formation of a new phase, mullite. In case of well-crystallised kaolinite this peak appears close to 1000°C (Tamás, 1970).

Based on the mass losses corresponding to the water loss of kaolinite, the amount of kaolinite present in the samples was estimated together with the total mass losses and the results are also presented in Table 1. The results show that the kaolinite contents of samples are similar, varying between 36-40 %.

Methods

Calcination

Air-dried clay samples were crushed and sieved through a 0.2-mm sieve. The undersize was oven-dried at 105°C for 24 hours and then calcined in an electric kiln in batches at 600, 700, 800, 900 and 1000°C. The calcined clays were ball-milled and passed through a standard 75-µm sieve and the undersize used for the tests.

Compressive strength

In order to determine the optimum calcination temperature for each clay sample, the compressive strengths of the pozzolanas were tested by blending them with Portland cement using cement replacemnet of 20% by mass. The pozzolanas and the cement were blended first and then the aggregates as specified by BS EN 196-1 (BSI, 1996). A binder (cement and pozzolana) to sand ratio of 1:3 was employed. Afterwards, water needed was added and mixed for about 4 minutes. A water binder ratio of 0.42 was used to obtain a workable mix.

Mortar test cubes were then prepared in 76-mm cube metal moulds. The moulding involved tamping the mortar and vibrating the mould for 2 minutes. After keeping the moulds under wet sacks for 24 hours, the cubes were demoulded and cured in water at 22°C for 28 days. The mortar cubes were then tested for compressive strength.

Setting time

The Vicat apparatus was used to determine the standard consistencies and setting times of the pozzolana cements and Portland cement as specified by BS EN 196-3 (BSI, 1996).

RESULTS AND DISCUSSION

Compressive strength

The average compressive strengths of 10 mortar cubes for the different calcination temperatures are presented in Table 2.

Table 2. 28-day compressive strengths of clay pozzolana cement mortar cubes at 20% cement replacement

Sample	Calcination temperature, °C				
	600	700	800	900	1000
	28-day compressive strength, N/mm²				
AS	25.4	33.4	34.9*	33.8	-
HW	14.8	15.2	16.1	26.9*	10.4
MN	24.8	36.2	37.6*	31.9	-
NK	34.1	29.9	26.3	36.4*	-

* Maximum compressive strengths

All samples on calcination showed some pozzolanic activity at all temperatures and had compressive strengths higher than the minimum standard value of 24.1 N/mm² required for both concrete and general constructions (ASTM, 1979). Hwereso clay, however, attained this minimum value at only 900°C. The optimum calcination temperatures at which the highest compressive strengths were obtained are marked in Table 3. In case of Nkonsia clay calcination at 600 and 900°C gave comparable results, however, for cost saving on energy the lower temperature is chosen as the optimum.

It is observed that Hwereso clay gave the lowest compressive strengths even at its optimum firing temperature of 900°C. It had the lowest SiO_2 content and SiO_2 to Al_2O_3 ratio. These constituents are the most essential for pozzolanic activity. However, it is not possible to prove strong correlation between the optimum firing temperature, compressive strength and the SiO_2 or Al_2O_3 content or kaolinite content of the other samples. It is also noted that the Mankesim clay at the optimum firing temperature of 800°C gave a higher compressive strength than the control mix of 36.5 N/mm² which did not contain pozzolana but only ordinary Portland cement.

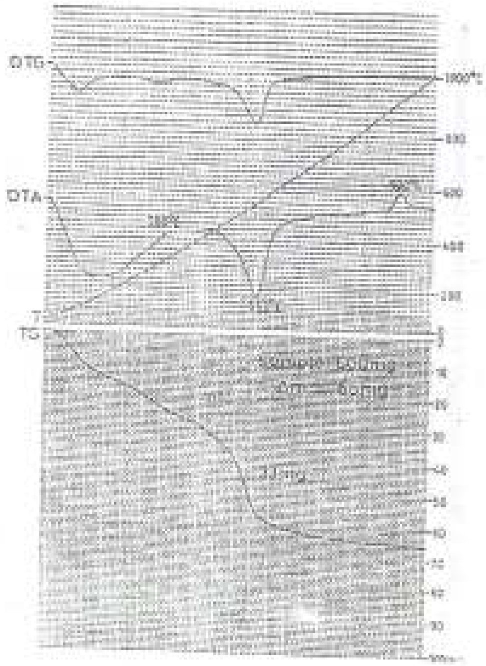

Fig. 5 Thermograms of Asokwa clay

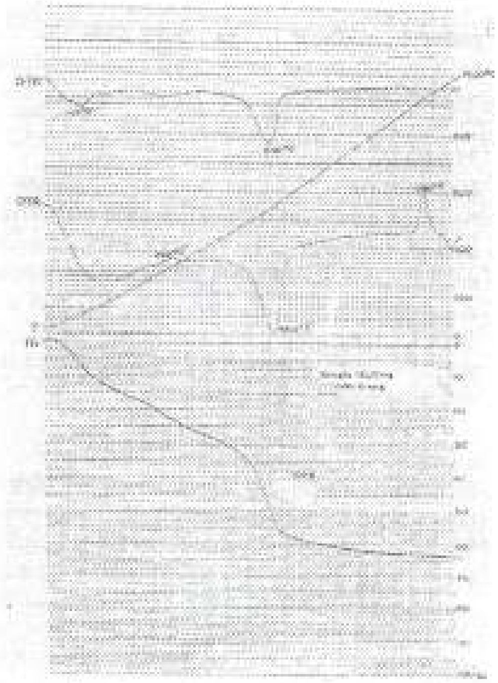

Fig. 6 Thermograms of Hwereso clay

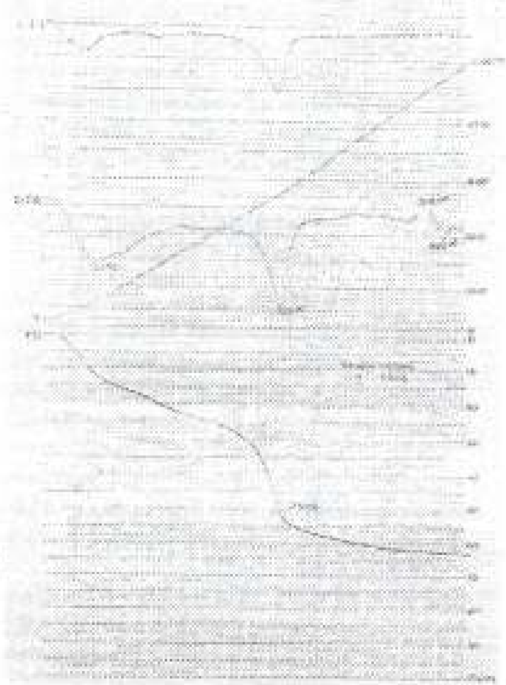

Fig. 7 Thermograms of Mankesim clay

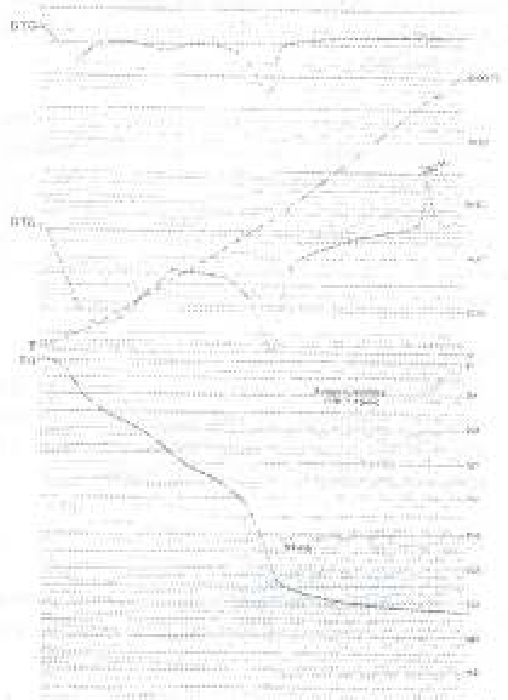

Fig. 8. Thermograms of Nkonsia clay

Standard consistency and setting times

The standard consistency and the final setting times of the pozzolana cements and ordinary Portland cement were determined at their respective optimum temperatures. These are shown in Table 3. The standard consistencies of the pozzolana cements were a little higher than that of Portland cement.

Table 3. Standard consistency and setting times of pozzolana cements

Sample	Standard consistency, %	Setting time, min	
		Initial	Final
AS	38.1	97	265
HW	37.4	100	274
MN	38.0	98	269
NK	37.9	99	265
Control	37.3	105	280

This was expected since clays have lower specific gravities than cement and thus would require larger volume of material to replace the same mass of cement. Consequently, clay pozzolana cements require more water in the preparation of mortars and concrete as compared to Portland cement. However, pozzolana cements set faster than Portland cement but still fell within the standards (BSI, 1992).

CONCLUSION

The analysis of clay samples showed that except for significant differences in the Fe_2O_3 content impacting different coloration to the clays, the SiO_2 and Al_2O_3 contents are similar. The main mineralogical components are also quite similar with the main clay mineral being kaolinite of 36-40 % and quartz. Pozzolanic activity of the clays was developed by calcining them at temperatures between 600-1000°C. The optimum calcination temperatures are 800°C for the Asokwa and Mankesim clays, 900°C for the Hwereso clay and 600°C for Nkonsia clay. The study shows that all four clays are suitable pozzolanas, which can be used to partially replace ordinary Portland cement for both concrete and general construction in housing.

ACKNOWLEDGEMENT

The XRD and thermal analysis were performed at the Department of Silicate Chemical Technology, University of Veszprém in Hungary.

References

American Society for Testing and Materials, Annual Book of ASTM Standards, Part 13, Cement; Lime; Gypsum and Related Building Materials and Systems, Philadelphia, pp. 87-360, 1979

British Standard Institution, Standard specification for Portland cement, BS 12, B.S.I., London, pp. 37, 1992

British Standards Institution, Standard methods of test for soils for civil engineering purposes, BS 1377, B.S.I., London, pp. 62, 1990

British Standard Institution, Method of testing cement, BS EN 196-1, B.S.I., London, pp. 19, 1996

British Standard Institution, Determination of consistency and setting times, BS EN 196-3, B.S.I., London, pp. 12, 1996

Frempong, E. M., and Atiemo, E., Evaluation of Nkonsia clay for brick and tile production, Technical Report, BRRI, Kumasi, Ghana, pp. 9, 1992

Hammond, A. A., Hydration Products of Bauxite-Waste Pozzolana Cement. The Int. Journal of Cement Composites and Lightweight Concrete, Vol. 9, No.1, pp. 19-31, 1987

Lea, F. M., The chemistry of cement and concrete, Edward Arnold, London, pp. 414-453, 1970

Malhotra, V. M., The use of fly ash, slag, silica fume and rice-husk ash in concrete. A review in CBU/CANMET International Symposium on Use of Fly Ash, Silica Fume, Slag and Other By-Products, Milwuakee, Wisconsin, August 1992

Tamás, F., Szilikátipari laboratórium vizsgálatok *(Laboratory tests in the silicate industry)*, Müszaki Könyvkiadó, Budapest, pp. 276-289, 1970

Wild, S., Observations on the use of ground waste clay as a cement replacement material, Building Research and Information, Vol. 24, No. 1, Chapman and Hall, London, pp. 35-40, 1996

Wild, S., Gailius, A., Hansen, H., Pederson, L., and Szwabowski, J., Pozzolanic properties of a variety of European clay bricks, Building Research and Information, Vol. 25, No.3, pp. 170-175, 1997