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Effect of Lime on Physical Properties of Natural Pozzolana from Same, Tanzania

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Abstract— **There is an increasing interest on researching for appropriate technology to develop local materials for masonry works. This research investigates the effect of hydrated lime on the physical properties of natural pozzolana from Same, Tanzania. The effect of lime is analyzed by pH, Atterberg limits, and initial rate of water absorption tests. The lime content is maintained at 3 – 12% percentages by weight of dry mass. The lime increases the pH of lime-treated materials to greater than 12, which is necessary for pozzolanic reaction. The plasticity index (PI) values of lime-treated materials decrease with the increase in lime amount. The rate of water absorption of lime stabilized unfired and compressed brick specimens decreases with lime content. The observations from the study have shown that hydrated lime improves physical properties of natural pozzolana of Same, Tanzania.**

Keywords— Lime stabilised unfired and compressed pozzolana brick, plasticity index, and atterberg limit

I. Introduction

There is a shortage of low cost and environmentally friendly housing in Tanzania and developing countries as well. This has led to many investigations into new building materials [1]. The development of locally available materials could alleviate the problem. Natural pozzolana has been reported to be one of alternative local raw materials [1]. Its occurrence is worldwide [2]. In Tanzania large deposits are found in northern, eastern and southern areas. Pozzolana is composed mainly with silica and alumina. As it is in natural form, pozzolana lacks binding properties. It is, therefore, not sustainable when it's made into unfired compressed brick. The stabilizing agents like cement and hydrated lime are used to improve their binding properties which result in development of strength and durability.

Hydrated lime has advantages over cement. Studies show that hydrated lime requires less energy and simple equipments during their production [3]. This will ultimately have advantages in cost reduction as well as safe guarding the environment. The low cost makes hydrated lime stabilization as an appropriate method in developing countries Tanzania in particular.

Pozzolana are divided into two types; natural and artificial. The natural pozzolana occurs in nature. They may either be volcanic ash (as a result of volcanic eruption) or types of clay with appropriate mineral content for pozzolanic reaction. Artificial pozzolana are those obtained from the industry like pulverized fly ash (PFA) and furnace slag [4]. The developing countries are not industrialized; therefore there is a scarce availability of artificial pozzolana.

The physical properties of natural pozzolana with addition of hydrated lime are changed in two ways. Firstly, when lime is added, the agglomeration and flocculation of particles take place resulting into the formation of larger particles [5]. The larger particles reduces the plasticity index values and increases workability which in turn improves the compaction properties [6] . Secondly, when lime mixed with natural pozzolana and water it increases the pH values to greater than 12. The cementing products are then formed which are Calcium-Silicate-Hydrate (CSH) and Calcium – Aluminates - Silicate (CAS) [7]. The formation of these cementing products reduces the degree to which the materials absorb water. This will enable them to be less sensitive to changes in moisture content which improve its durability [3].

It has been reported by Dallas, N.L and Nair, S. [8] that materials suitable for lime stabilization have plasticity index greater than 10% and more than 25% of materials passes sieve size75µm. The study carried out by Amu, O.O et al. [9] shows that the amount of lime for stabilization depends on reduction of plasticity. Other results indicated that the quantity of lime needed to effectively treat the clays to develop increased strength varies with the type of clay mineral present [10].

The objective of this work is to determine the hydrated lime effect on physical properties of the natural pozzolana from Same, Tanzania. The physical properties are analyzed using pH, atterberg and water absorption tests.

II. EXPERIMENTAL PROCEDURE

A. *Materials*

The main materials are natural pozzolana, lime and water. Natural pozzolana samples are taken from Same, Tanzania at depth ranging between 1.5 to 2 m from ground level. The lime used is purchased from commercial suppliers of building materials. The analysis of basic properties of collected natural pozzolana samples is carried out and results summarized in

Table 1. The chemical composition results reported by Hashimu Hamisi et al. [11] is as shown in table 3..

TABLE 1: BASIC PROPERTIES OF NATURAL POZZOLANA FROM SAME

Physical properties	
Liquid limit	69%
Plasticity index	36%
Maximum dry density	1.441g/cm^3
Optimum moisture content	23%
Specific gravity	2.62
Soil classification	CH
pH	6.2
Particle grading (%)	
2mm - 75µm	31
< 75µm	69

B. Methods

The natural pozzolana samples are air dried and grounded by hand to fine size particles. The lime content is varied based on previous studies of lime stabilization. The range between 3 – 12% of lime by weight of dry mass is adopted in this research. The samples are marked with the format of S_i where S stands for sample and i for lime content in % by weight as shown in Table 2. The 0% of lime by weight is kept as reference or control mix. It must be noted that in order to achieve more accurate results for each composition of lime three tests are performed and the average of three results is reported.

TABLE 2: MIX PROPORTIONS OF HYDRATED LIME AND NATURAL POZZOLANA OF SAME, TANZANIA

Designation		S_0	S_3	S_5	S_8	S_{10}	S_{12}
Sample mixes, % by weight	Natural pozzolana	100	97	95	92	90	88
	Lime	0	3	5	8	10	12

TABLE 3: CHEMICAL COMPOSITION OF NATURAL POZZOLANA FROM SAME, TANZANIA

SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	MgO	Na_2O	K_2O	LOI
62.1	23.5	2.62	1.55	0.02	0.09	0.02	0.08	10.03

Grain size analysis.

The grain size analysis of pozzolana samples involves computing the percentage by mass of particles within the different size ranges [12]. The grain size analysis is also used in materials classification. The wet sieving method is adopted in this work where the minimum sieve size is 63µm. The test procedures are carried out in accordance to British standards [13].

Initial Consumption of Lime (ICL)

The pH test is the method normally used to estimate lime content for stabilization [14]. The test help to determine sufficient quantity of lime to satisfy cation exchange, flocculation, agglomeration, and pozzolanic reactions [14]. The ICL in this work is determined using Thermo Scientific Orion 4-Star bench top pH/Conductivity meter. Samples of materials are sieved through No. 20 (0.425mm) mixed with water at different proportions of lime. (Range of 3 – 12% by weight). The test procedures are according to British standards [15].

The Atterberg limits

The materials passing sieve size 0.425mm (sieve no. 40) are used. Liquid limit (LL) is determined according to procedures set by British standards [13]. The drop cone method is used whereby the result is the moisture content at which an 80 g, 30^{o}cone sinks exactly 20 mm into a cup of remoulded material in a 5 seconds period. The plastic limit (PL) is the water content in which material begins to crack when rolled between the fingers on glass plate to form a thread of 3 mm diameter. At this point, the materials have a stiff consistency. The variations in the plasticity index of the natural pozzolana at different lime percentage are then studied. Both liquid and plastic limit tests are executed at room temperature. The difference between LL and PL is plasticity index. The liquid limits (LL) and plastic limits (PL) depict the water content boundaries relating non-plastic, plastic and viscous fluid states. The plasticity index (PI) of materials mark out the complete range of plastic condition as illustrated by Fig. 1.

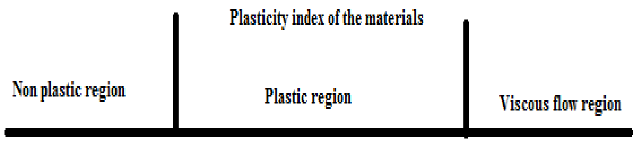

Fig.1. Atterberg limit illustrations

Water absorption

The principle of absorption testing is to immerse a face of the masonry unit in water for a particular period and determine the increase in mass. The brick is immersed in 5mm depth of water for 10 minutes. The gross area of test face and the increase in brick weight are measured [16]. The set up is as shown in Fig.2. The initial rate of absorption (IRA) is calculated as the ratio of increase in mass and gross area in 10 minutes. The water absorption is the ratio of increase in mass and dry mass expressed in percentage.

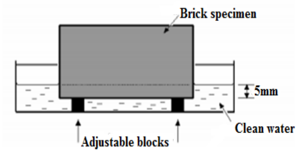

Fig.2. Experimental setup of Initial rate of water absorption

III. RESULTS AND DISCUSSION

A. *Chemical composition*

The results of chemical analysis are illustrated in Table 1. The presence of high percentage of SiO_2 (62.1), Al_2O_3 (23.5) and Fe_2O_3 (2.62) show that the natural pozzolana have amount of silica, alumina and Iron oxide greater than 70% which is the minimum requirement chemical composition for lime stabilization [17].

B. *Grain size analysis*

The grain size analysis is represented in Fig.3. From the plot, the materials finer than 75µm are 69% (> 25% recommended for lime stabilization). For uniform grain size distribution with sufficient fines, the voids are mostly filled. This increases the density and reduces permeability. The both density and permeability have influence on materials performance with regards to strength and durability.

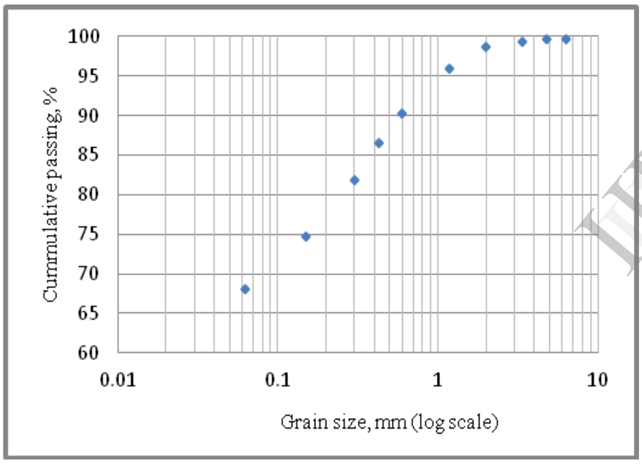

Fig.3. Grain size analysis plot of natural pozzolana from Same, Tanzania

C. *pH of raw materials*

Temperature is an important factor on pH values. Higher temperatures reduce the solubility of lime and therefore decrease pH values slightly [18]. The plot of pH values corrected at 25^0C versus lime content is as illustrated in Fig. 4. From the results the pH values increases from 6.2 at 0% lime to 12.44 at 12% lime. There is a substantial increase of pH values with addition of lime. Above 8% lime, the pH values starts to even out. The lime content at this point have pH value necessary for pozzolanic reaction known as initial consumption of lime (ICL) [18]. The silica and alumina components are then dissolved out of the structure of natural pozzolana and make it available to react with Ca^{2+} to form cementing products of calcium silicates. The formed cementing products change the physical properties by reducing the degree of water absorption. This will improve its durability.

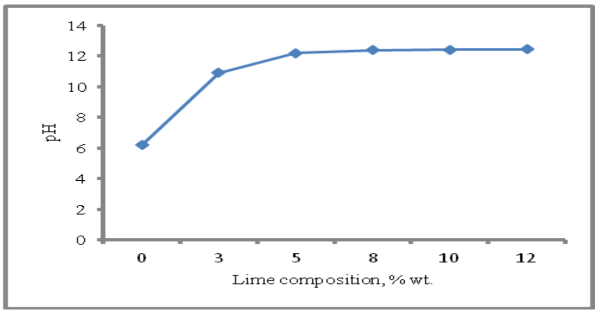

Fig.4. Effect of lime on pH values of lime-treated natural pozzolana

D. *Attreberg limits*

The results of Atterberg limits for natural pozzolana samples from Same, Tanzania are analyzed in this section. The results indicate how additions of lime in natural pozzolana have effects on its physical properties.

Liquid and plastic limits

The trend indicates the decrease in liquid limit (LL) and increase in plastic limit (PL) with addition of lime as illustrated in Fig.5. The liquid limit decreases from 69% at 0% lime to 59% at 12% lime. In case of plastic limit, the values increase from 32% at o% lime to 42% at 12% lime. The change is significant for both liquid and plastic limits up to 8% lime thereafter no considerable changes are noted. A study conducted by Asma [19] has the same trend .

The reduction of liquid and plastic limits can be explained as the results of cation exchange and agglomeration-flocculation process. The agglomeration- flocculation process leads to formation of coarser particles [5]. The coarser particles reduce the surface area resulting in less water adsorbed.

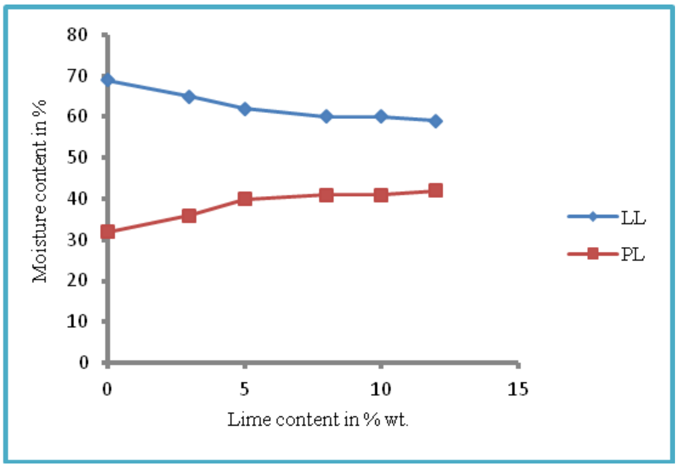

Fig.5. Effect of lime on liquid and plastic limits of natural pozzolana from Same, Tanzania

Plasticity index

The effect of lime on plasticity Index (PI) of the lime - treated materials is shown in Fig.6. The values of plasticity index decreases with the increase in lime content. The values decreases from 37% at 0% lime to 17% at 12% lime. At lime content of 8%, a maximum reduction in PI of 19% is obtained beyond which no significant change is noticed. Hydrated lime in the presence of water produces an alkaline condition. This will cause the reaction between hydrated lime and pozzolana containing silica (SiO_2) and alumina (Al_2O_3). The reaction result into the agglomeration of fine clay particles into coarse particles through exchange of cation making the materials behave like silt rather than clay [5]. The formation of coarse particles reduces the surface area which reduce water content and ultimately reduces the plasticity index [6]. This makes the materials easily workable hence improving the compaction

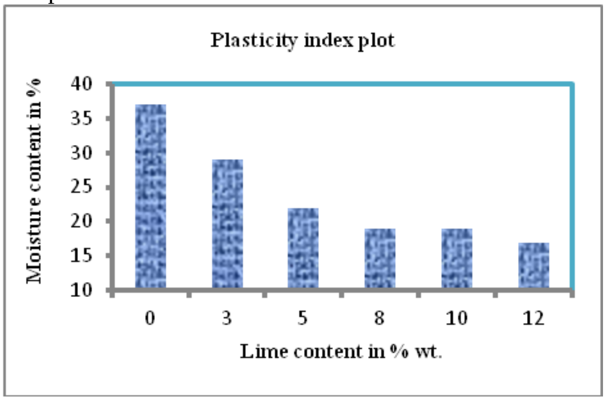

Fig.6. Effect of lime on plasticity index of natural pozzolana from Same, Tanzania

E. Water absorption

The brick specimens without lime collapsed during testing. However, the lime stabilized specimens are observed to be stable to water damage. The influence of lime content and moulding pressures on initial rate of absorption (IRA) are illustrated in Fig. 7. The IRA values decrease with the increase proportions of lime and moulding pressures. The decrease of IRA with lime content can be due to pozzolanic reaction, forming cementitious materials which are more impermeable. The formation of cementitious matrix of calcium silicates and aluminates occur when lime raises the pH of lime-treated pozzolana to above 12 [7, 18]. The results are supported by study done by Guettala, A. et al. [20].

For particular lime content, it is observed that the increase of pressure reduces IRA. This is because the increase in moulding pressure tends to reduce porosity.

The result from all brick specimens fulfils the requirements. The minimum value of IRA without significant affecting the masonry wall is $2kg/m^2$.min [16]. Bricks with large IRA values will draw moisture from the mortar and reduce its effectiveness [16].

The percentage water absorption (WA) of tested brick specimens decreases with lime content and moulding pressure similar to IRA (Fig. 8). The trend is due to formation of less permeable cementing matrix and reduction of porosity as for IRA. For stabilized unfired and compressed bricks, the acceptable maximum limit of water absorption is at 20% [16]. From Fig. 8, the moulding pressure of 8MPa is found to be appropriate as the water absorption values are within the acceptable range. The values ranges between 14% at 5% lime to 10% at 12% lime.

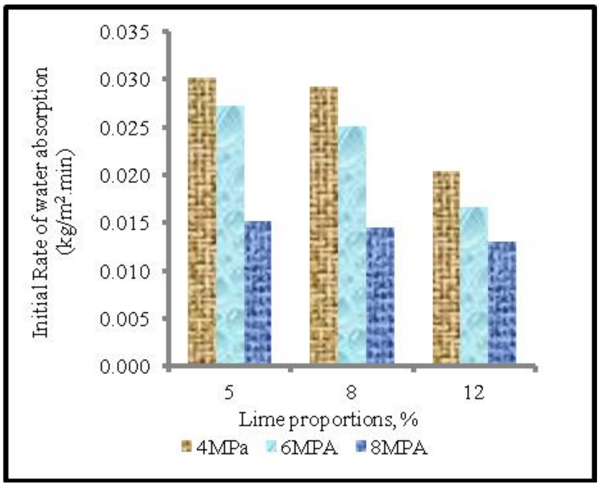

Fig.7. Effect of lime and moulding pressure on water absorption coefficient of natural pozzolana from Same, Tanzania

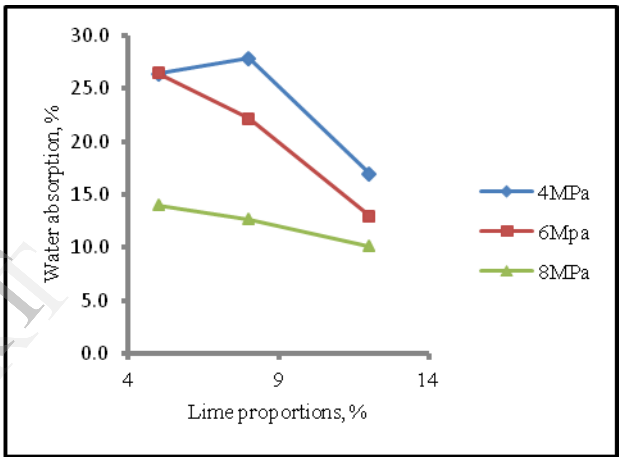

Fig.8. Influence of water absorption on lime content and moulding pressure of natural pozzolana from Same, Tanzania

IV. CONCLUSION

In this study, the test results indicate that the plasticity index decreases with addition of lime as coarser particles are formed. This enhances the compaction properties by increasing density and reducing porosity. The increase in density and decrease in porosity bring about strength and durability of materials.

The addition of lime to natural pozzolana results in the formation of cementing products of calcium silicates and aluminates which are less permeable. This is observed as the initial rate of water absorption of fabricated brick specimens decreases with the increase in lime content. The results suggest that the addition of hydrated lime reduces the possibility of water deterioration. Therefore, the reduction of water absorption rate increases the integrity of the materials by improving the strength and durability.

From the observations, it can be concluded that the lime as a stabilizer has effect on physical properties of the materials under study. The physical properties improved being plasticity index and water absorption which tends to improve the performance of materials. Therefore, the natural pozzolana of Same, Tanzania can be developed for unfired and compressed bricks at low cost.

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