Physical Properties of Katsi-Cement Pozzolanic Mortar

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Abstract

This paper is the result of an experimental investigation into the physical properties of katsi-cement pozzolanic mortar. Six mortar mixes of 1:6 cement: sand, with some part of the cement replaced by katsi in the order of 0%, 10%, 20%, 30%, 40%, and 50% by weight of the cement, were designed for the various tests carried out. Tests for moisture absorption, durability and compressive strength indicated that the katsi –cement pozzolanic mortar has its moisture content decreasing with increase in katsi content, durability increases as the katsi content increases and compressive strength increases with increase in age but decreases with increase in katsi content. Thus katsi is a good pozzolanic material for partial replacement of cement in mortar, especially if the mortar is to be used in an acidic environment.

Various materials, be they natural or artificial have been used as pozzolanas in partial replacement of concrete and or mortar with encouraging results. This paper examines the physical properties of mortar containing katsi as a pozzolana used in partial replacement of cement in the mixes.

Pozzolana is a natural or artificial material containing silica in a reactive form. A more formal definition by ASTM Specification C618-78 is that it is a silicious-alluminous material which in itself possesses little or no cementious value but will, in finely divided form and in the presence of moisture, chemically react with calcium hydroxide at ordinary temperature to form compounds possessing cementicious properties (Lea, 1970). Katsi on the other hand is the Hausa name given to the bye-product of indigo (dye residue) which is predominantly carried out in Hausa land (Northern Nigeria).

The Coconut Katsi) is formed by the following process: the barks of oak tree (baba in Hausa) is soaked in water in a dye-pit and ashes from burnt wood and indigo (shuni0 is added and the mixture is stirred for days. The bottom deposit of the mixture used for dying clothes is removed, dried, fired to grey ash and pounded into powder called katsi.

Literature review indicates that the following have been used as pozzolanas with replacement of Ordinary Portland Cement (OPC) in the range of 10 to 40 percent of the pozzolana. The pozzolanas include the following: volcanic ash (Smith, 1993); fly ash (Owens 1979, Berry and Malhotra 1980, Smith and Halliwell 1979, and Bamfort 1980); Rice Husk As (RHA) (Mehta 1975 and 1977, Cook rt al 1977, Loo et al 1984, 1988, and 1993, Okereke and Obeng 1985, and Rahaman 1986; Bagasse ash (Mohammedbhai and Baguat 1985); calcined basalt stone (Smith 1994); and Blastfurnance Slag (Smith 1994).

Experimental Procedures

Mix Ratios

in order to find the effect of katsi on some properties of mortar, six mixes of 1:6 cement: sand, with some part of the cement replaced by katsi in order of 0%, 10%, 20%, 30%, 40%, and 50% by weight of the cement , were designed. Trial test were carried out to determine an optimum w/(c+k) ratio for each mix. Table 1 shows the summary of the mixes used.

Table 1 Mortar Mixes

Mix No.	Mix ratio (c+k) : Sand	w/ (c+k) ratio
MM- 1/0	(1.0+0.0) : 6	0.75
MM- 2/10	(0.90+0.10) : 6	0.79
MM- 3/20	(0.80+0.20) : 6	0.85
MM- 4/30	(0.70+0.30) : 6	O.90
MM- 5/40	(0.60+0.40) : 6	0.95
MM -6/50	(0.50+0.50) : 6	1.00

A total of one hundred and eight mortar cubes of size 70.7mm were cast for the tests on moisture absorption, compressive strength, and durability of mortar. The procedure for individual test is presented below.

Moisture Absorption

The moisture absorption test was carried out in accordance with Norton's procedures (1986). Three mortar cubes were prepared from each of the six mixes given in table 1 and were cured for seven days by moist curing. At the end of the seventh day, the cubes were weighed and placed in an oven to further dry out, at a temperature of about 100□C. They were left in the oven until no further decrease in weight was noticed and the final weight was noted and recorded.

The cubes were then kept under constant saturation for a period of seven days and weighed. The increase in weight of the wet sample as a percentage of the dry weight determines the moisture absorption rate of the sample, and is expressed thus:

% Moisture content = (increase in weight of cube/final weight of cube) x 100

The variation of moisture absorption of mortar with katsi content is shown in Table 2.

Table 2 Results of Moiture Absorption Test for Mortar

Mix mo.	Katsi content (%)	Average moisture absorption (%)
MM-0/1	0	14.69
MM-10/1	10	14.30
MM-20/1	20	13.86
MM-30/1	30	13.18
MM-40/1	40	13.27
MM-50/1	50	12.80

Durability

In order to find the effect of katsi on the durability of mortar, three mortar cubes produced from each mix were immersed in 5% solution of sulphuric acid.

At the end of 28 days of casting and curing, three mortar cubes from each mix were remove and kept for 48 hours to dry. They were then weighed to determine their weights before immersed in 5% solution of surphuric acid in a plastic bowl. After 28 days of immersion, the mortar cubes were removed from the plastic bowl, rinsed thoroughly in clean tap water and air-dried in the laboratory for 48 hours. They were weighed to determine their new weights. The durability is calculated in terms of weight loss after 28 days of immersion in the acid.

% weight loss = (wt. before immersion – wt. after immersion) / (wt. before immersion) x 100.

The effect of katsi on the durability of mortar is illustrated in table 3. Durability here is a measure of weight loss of mortar cubes after immersion in 5% solution of sulphuric acid for a period of 28 days.

Table 3 Results Durability Test on Mortar

Mix no.	Katsi content (%)	Weight loss (%)
AMM- 0/1	0	7.8
AMM- 10/1	10	7.00
AMM-20/1	20	5.10
AMM-30/1	30	3.80
AMM40/1	40	3.10
AMM-50/1	50	2.10

Compressive Strength

The test for compressive strength was carried out in accordance with BS 1881 (1970) using the Universal Testing Machine. The mortar cubes were crushed at the ages of seven and twenty eight days to determine the compressive strength.
The variation of compressive strength of mortar with katsi content is shown in Table4

Table 4 Results of Compressive Strenght of Mortar At The Age of 7 And 28 Days

Mix no.	Katsi content (%)	Average compressivestrength (N/mm2)	
		7days	28 days
MM-1/0	0	6.3	7.3
MM-2/10	10	6.1	6.8
MM-3/20	20	4.6	5.8
MM-4/30	30	3.7	4.5
MM-5/40	40	3.2	3.7
MM-6/50	50	2.5	2.9

Discussions

Mix Ratio

It can be observed that water – (cement + katsi) ratio increases with an increase in the katsi content. Without katsi, the water/ cement ratio for optimum strength is 0.75. This is increased to 0.79 with 10 percent content of katsi and 1.0 ratio for 50 percent katsi content. This implies that the more the katsi content the more the water required for mixing the constituents.

Moisture Absorption

Test result of moisture absorption was shown in table 2 and the graph plot is shown in figure 1 below.

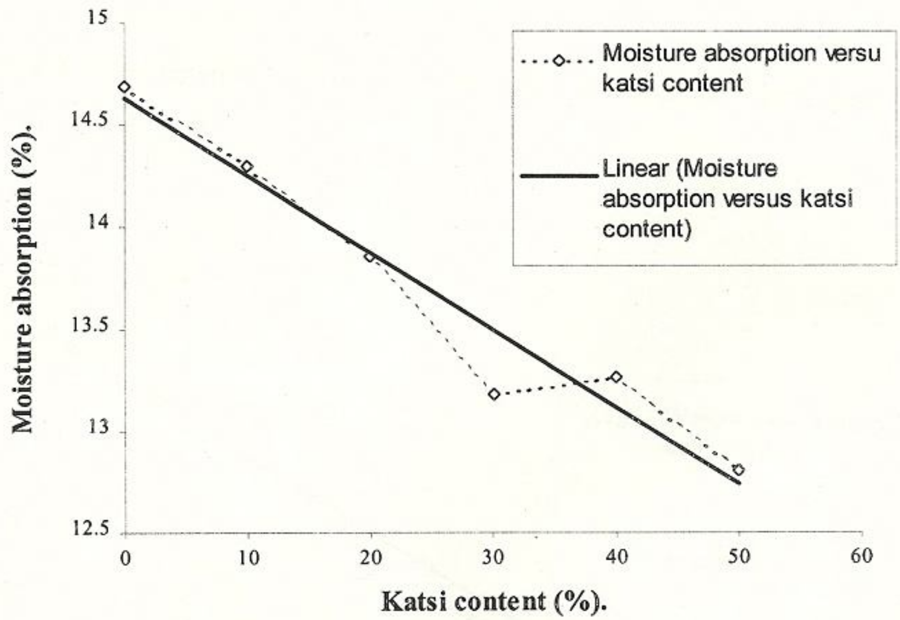

Fig. 1 Variation of moisture absorption of mortar with katsi content.

The moisture absorption of mortar decreases with increase in katsi content. With the incorporation of up to 50% katsi, the moisture absorption reduces from 14.69% to 12.80% (i.e about 13% reduction).

The Na_2O in katsi probably accounts for the waterproofing properties of katsi-cement mortar, which is responsible for the reduction in moisture absorption.

The equation for the graph is:

$$y= 14.63- 0.04x \qquad \text{equation 1}$$

Where y is moisture absorption of mortar in % and x is the katsi content in %. With this equation, the moisture absorption of mortar for any given katsi content can be determined.

The coefficient of determination for equation 1is 0.95

A comparison of the moisture absorption values of the mortar with the ASTM Standard Specification given in the appendix shows that for all katsi contents, the values meet the specification.

Durability:

Test results were shown in table 3 and the variation of weight loss with respect to katsi content is shown in figure 2 below.

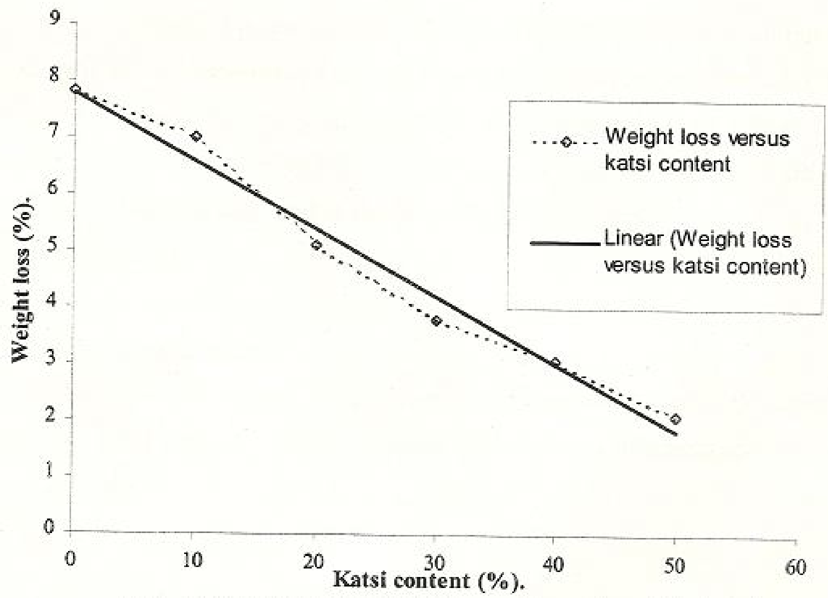

Fig. 2 Variation of weight loss of mortar with katsi content.

The graph shows that the weight loss of mortar decreases with increase in katsi content. It implies that katsi reduces the weight loss of mortar due to the acidic effect which, in turn, indicates improvement in durability of mortar in acidic environment. The weight loss decreases from 7.8% for mortar without katsi to 2.1% for mortar with 50% katsi.

The equation generated for the graph is:

$$y_1 = 7.78 - 0.21x_1 \quad \text{……………………….equation 2}$$

where y_1 is the weight loss of mortar in % and x_1 is katsi content in %. This equation can be used to find the weight loss of mortar for any given katsi content. The coefficient of determination for equation 2 is 0.98

The reason for the improvement of the durability of mortar with the incorporation of katsi is explained as follows: the presence of $Ca(OH)_2$ in the hydration products of Portland Cement is primarily responsible for poor resistance of Portland cement mortar or concrete exposed to acid attack. The mechanism of the acid attack is explained thus: for instance, sulphuric acid (H_2SO_4) reacts with the Calcium hydroxide ($Ca(OH)_2$ in the hydration products to produce first, a secondary gypsum ($CaS0_4.2H_2O$). the gypsum reacts with tricalcium aluminate, C_3A, of the cement to form calcium sulphoaluminate hydrate (ettringite), $C_3A.3CaSO_4.31H_2O$, which leads to swelling, expansion, and disintegration of the mortar or concrete. The equation for these reactions can be represented below according to Steinour (1952).

(i) $H_2SO_4 + Ca(OH)_2 \rightarrow CaSO_4.2H_2O$

(ii) $3CaSO_4.2H_2O + 3CaO.Al_2O_3 + 29H_2O \rightarrow 3CaO.Al_2O_3.3CaSO_4.31H_2O$
Calcium sulphoaluminate hydrate or ettringite)

On the contrary, the pozzolanic reaction between katsi and $Ca(OH)_2$ liberated during hydration reduces the concentration of $Ca(OH)_2$ in the solution thereby reducing the concentration of gypsum that causes the swelling, expansion and disintegration of mortar or concrete. The equation for this reaction is: $3Ca(OH)_2 + SiO_2 \rightarrow 3CaO.SiO_2 + 3H_2O$. Furthermore, the high concentration of Na_2O in katsi makes the resulting products alkaline, and this effect reduces the acid attack. (Ella, 2001).

Compressive Strength

Table 4 shows the average compressive strength for seven and twenty eight days of age with corresponding kastsi content. Figure 3 shows the variation of compressive strength of mortar with katsi content.

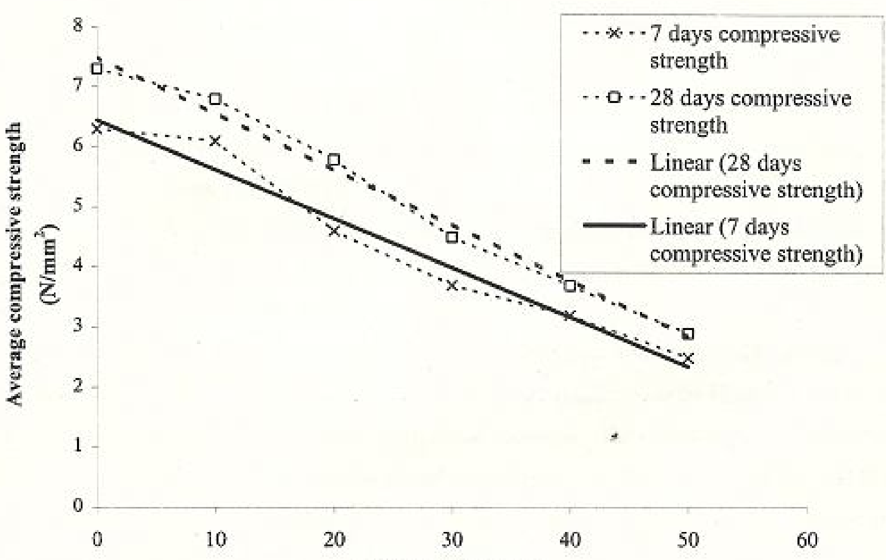

Fig. 3 Variation of average compressive strength of mortar with katsi content.

The compressive strengths at the age of 28 days are higher compared with those at age of 7 days, which indicates that compressive strength increases with increase in age. The compressive strengths for both the 7 and 28 days decrease with increase in katsi content. The reasons for this phenomenon are as explained below:

The first reason is because the katsi content increases and the cement content decreases, the C_3S compound, which accounts for the bulk of the strength development in the mixture of cement and katsi also reduces (even for katsi content above 20% C_3S ceases to exist). It is only C_2S, which contributes little to the strength development that increases as the katsi content increase (Ella, 2001). The second reason is because the high concentration of SO_3 in katsi (Ella, 2001) is detrimental to strength development of the mortar or concrete in the following ways: the SO_3 in katsi in excess of the value prescribed by BS12: 1978 for cement favours the formation of gypsum, which reacts with C_3A to form calcium sulphoaluminate hydrate (ettringite), $C_3A.3CaSO_4.31H_2O$. This ettringite is a weak product that can cause swelling and disruption of the end product compared with calcium silicate hydrate formed during the hydration of cement alone and so the strength of the mortar or concrete is thus reduced. The equations of the reaction include:

(i) $SO_3 + H_2O \rightarrow H_2SO_4$

(ii) $H_2SO_4 + CA(OH)_2 \rightarrow CaSO_4.2H_2O$

(iii) $3CaSO_4.2H_2O + C_3A + 29H_2O \rightarrow C_3A.3CaSO_4.31H_2O$

Analysis of the graph produces the following equations:

$y_2 = 6.44 – 0.082x_2$…………………………… equation 3 - 7 days of age

$Y3 = 7.50 – 0.093x3$…………………………… equation 4 - 28 days of age

Where, y_2 = average compressive strength of mortar at the age of 7 days in (N/mm^2)

y_3 = average compressive strength of mortar at the age of 28 days in (N/mm^2)

$x_2 = x_3$ = katsi content in (%)

Equations 3 and 4 can be used to find the average compressive strength of mortar at the age of 7 and 28 days respectively for any given katsi content. The coefficient of determination, R^2 for equations 3 and 4 are 0.97 and 0.99 respectively.

A comparison of the compressive strength of the mortar at the mortar at the age of 28 days (given in Table 4) with the ASTM C90-75 and C129-75 Standard Specification for Hollow Load-bearing and Non-load-bearing blocks, respectively given in the appendix, the following can be observed:

(i) The compressive strength of the mortar without katsi, ($7.3N/mm^2$) meets the ASTM C90-75 Standard Specification for both grades N and S load- bearing block of compressive strength of $6.9N/mm^2$ and 4.8N/mm2 respectively.

(ii) The compressive strength of the mortar for 10% and 20% katsi (6.8Mpa and 5.8Mpa respectively) meets the ASTM C90—75 Standard Specification for Grade S hollow load-bearing block but does not meet the requirement for grade N hollow load- bearing block.

(iii) The compressive strength of the mortar for 30% katsi, ($4.5N/mm^2$) meets the ASTM C129-75 Standard Specification for non-load bearing block of compressive strength of 4.14N/mm2 while the compressive strenght5s of the mortar with higher katsi content do not meet the requirement as a result of the of the absence of C_3S at katsi content above 20%.

Conclusions and Recommendations

Conclusions

From the above discussions, it can be concluded as follows

The more the katsi contents in the mix, the more the water required to mix ingredients to obtain an optimum strength.

The moistuer absorption of mortar decreases with increase in katsi content. This makes the mortar less permeable. The moisture absorption can be obtained from the following equation:

$y = 14.63 – 0.04x$: where y = moisture absorption in (%) and x = katsi content in (%).

All the values of the moisture absorption satisfy the ASTM Standard Specifications.

The durability of mortar improves with increase in katsi content. The durability of the mortar can be assessed using the equation below:

$y_1 = 7.78 – 0.21x_1$: where y_1 = weigth loss (%) and x1 = katsi content in (%).

The compressive strength of the tested mortar increases with increase in age but decreases with increase in katsi content as a result of absence of tricalcium silicates.

The compressive strength can be estimated from the following equations:

a) $y_2 = 6.44 – 0.082x_2$: where y_2 = average compressive strength of mortar at the age of seven days in (N/mm^2) and x_2 = katsi content in (%).

b) $y_3 = 7.50 – 0.082x_3$: where y_3 = average compressive strength of mortar at the age of twenty eight days in (N/mm^2) and x_3 = katsi content in (%0.

Based on ASTM C618-78 requirement, up to 20% katsi content can be used for production of load- bearing blocks with compressive strength not less than $4.8N/mm^2$.

For non-load- bearing blocks with compressive strength not less than $4.14N/mm^2$, up to 30 percent of katsi content satisfy the ASTM code requirements.

A mortar of up to 50 percent of katsi content can be satisfactorily used for plastering work in areas of acidic environment.

The compressive strength of mortar with higher katsi content (i.e higher than 30%) does not meet with the requirement of ASTM for strength.

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Appendix A-1 : ASTM Requirements for Non Load-bearing and Load-bearing Blocks

Property	ASTM requirements
Compressive strength	
(1) Non load- bearing	
Individual unit	3.45Mpa
Average of 3 units	4.14Mpa
(2) Load- bearing	
Grade N	
Individual unit	5.50Mpa
Average of 3 units	6.90Mpa
Grade S	
Individual unit	4.10Mpa
Average of 3 units	4.80Mpa

Linear shrinkage (%)	Moistuer content (%) for job site Humidity conditions		
	Humid	Intermediate	Arid
0.03 or less	45	40	35
0.03-0.045	40	35	30
0.045-.0065, max	35	30	25