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Effects of Acid on the Strength Properties of Laterite Bricks Stabilized With Cement and Metakaolin

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ABSTRACT
This study aimed at evaluating the durability of laterite bricks stabilized with Portland cement (PC) and Metakaolin (MK) at various replacement levels of 2.5%, 5%, 7.5%, 10%, 12.5% and 15%) at water/cementitious ratio of 0.5. Control mix (0%MK) mix was designed to establish a comparative basis between mixtures blended with varying MK percentages. Both the control and mixes with MK were covered with weather-tied polythene during which the later mixes were cured with 2.5% dilute concentrations of H_2SO_4 & Hcl acids with an acidity pH of 1.8 each were sprinkled on the specimens independently at 7days intervals for 28 days. Their compressive strength (dry and wet), flexural strength, abrasion resistance, water absorption properties were compared to control samples (0%MK) and evaluated. The following results were recorded for dry compressive strength, wet compressive strength and flexural strength of (2.2 N/mm^2, 1.5N/mm^2 & 4.2N/mm^2 in Hcl) & (1.6N/mm^2 ,2.2N/mm^2 & 5.2N/mm^2 in H_2SO_4) at 10% MK replacement. It was found that, the rate of abrasion resistance increases with increased in MK content and decreased in

PC content and reverse was the case in water absorption property. Used of MK had improved water absorption property by 1% at all replacement levels. However, it can be concluded that, the specimens produced with mix set 10%MK + 5%C had met the minimum strengths requirements in accordance with; the Nigerian Industrial Standard (NIS), The Nigerian National Building Code (NNBC),2006 1.75Nmm2 with 5%C and the International British Standard which specifies minimum of 2.0 N/mm2 and The Nigerian Building and Road Research Institute(NIBRRI) specifies 1.65N/mm^2 and recommended for practical application. Therefore, beyond 10%MK replacement by weight of PC was not recommended in an acidic environment of Hcl and H_2SO_4.

1.0 **INTRODUCTION**

The durability of any building material is a measure of its ability to resist weathering and deteriorating agents. However, the ability of building material to easily get wet and the capacity to absorb and retain water for a long time are two properties that make it vulnerable to chemical and environmental deterioration (Neville, 1996 as was quoted by Ephraim *et al.*, 2016).

Ma'aruf *et, al.,* (2019) mention that global research has a tendency of having some research alternative in metakaolin development that has been caused by the high cost of convention materials, therefore there is a need to recycle agricultural and industrial waste for use in construction, in other to maintain ecological balances and challenges of housing are among those reasons. Those alternatives to widely acceptable include the use of pozzolana as an admixture and substitute to cement (Sule, 2012: Ma'aruf, 2016).

Laterite can be improved upon and used as building material for various types of structures by adding stabilizers, the result of which is stabilized laterite. Some commonly used stabilizers include: straw, dung, lime, cement and a combination of lime and pozzolana. Laterite soils are mixed with cement for economic and environmental purpose. However, the cement content in the additive should be as low as 3%possible (Yashwant *et al.*, 2015). Also, literatures have shown that the optimum proportion of cement/laterite ranges from (4 to 10%) by weight of cement to laterite soil.

Yaser, (2009) emphasized that the cement stabilization of laterite improves the durability and resistance to abrasion and water damage. Cement stabilization is preferred for laterite with high sand content (Fadairo, 2013). Stabilizers and other additives can also reduce swelling, shrinkages, cracking and increase strength (Birgit *et al.*, 2010). Aggarwaal and Holmes, 1983 that stabilized laterite with 3 to 7% of cement and the results showed particle size distribution, cement content, compaction effort and method of curing are factors which affect the strength of bricks. The compressive strength, flexural and direct tensile strength of soil-cement blocks are directly proportional to the cement content while initial rate of water absorption (IRA) is inversely proportional to the cement content (Otoko, 2014). Oyediran, (2011) reported that continuous increase in the quantity of cement used for stabilization is not guarantee for increase in improvement of some geotechnical properties. The minimum quantity of cement required to achieve adequate strength was 10% of laterite (Aguwa, 2009) though it depends on type of additives used. Similarly, it was observed that numerous studies are available on the strength properties of laterite stabilized with different additives (Osinubi *et al*.,2007 (Bagasse ash); Akerele *et al.,* 2021 (Synthetic foam); Abdulwahab *et al.,* 2018 (Natural latex rubber); Ayodele *et al.,* 2019 (Egg shell & Sawdust); Razanalatovo *et al.,* 2020 (Cassava starch); Obianyo *et al.,* 2020 (Bone ash & Hydrated lime); Meshida *et al.*, 2011 (Hydrated lime); Sackey, 2014(Polypropylene rope); Yashwant, 2015(Cement & aggregate); Olutage *et al*., 2018 (Cement & Lime); Nounagnon *et al*., 2018 (Treated & untreated pineapple leaves fibres)., Awoyera *et al.,*2020 (Plastic fibre) but, investigation on the effects of acid on the strength properties of laterite bricks stabilized with cement and metakaolin to acidic environments attack has not yet been explored. Therefore, this research work intends an effort towards filling that gap.

Due consideration is essential to include both the physical and chemical effects of all environmental conditions to which the structure may likely be exposed to during its service life (Mehrotra, 2009). An acids rain was one of the most constructional challenges that threaten the durability of construction Shakir and Mohammed (2015). Thus, sometimes the foundation conditions of the structure are acidic or the structure is exposed to acidic environment whether intentionally or unintentionally. Thus, the need to search an indigenous and suitable alternative building material is required to reduce over dependence on the use of cement remains a focus of many researchers around the world (John *et al*., 2005; Agbede and Manaseh, 2008; Bignozzia, 2011; Fadairo, 2013 and Akadiri *et al*., 2013).

The largest growth in carbon emissions from electricity generation, transport, industries and building operations are hazardous to human (Radhi, 2009). The over dependence on the utilization of sandcrete blocks for buildings have kept the cost of these units financially high (Aguwa, 2010). Also, sandcrete blocks is energy intensive because of the amount of cement used whose production involved high consumption of energy and emission of CO_2. Similarly, in Nigeria, an appreciable percentage of the entire population cannot afford to build their own houses, due to high cost of building materials (Daramola *et al*., 2005; Aguwa, 2009; James, 2009 and Olotuah, 2012). However, not all acidic deposition is wet. Sometimes, dust particles can become acidic as well and this is called dry deposition. When dry acidic particles and acid rain fall to earth, the nitric and sulphuric acid that make the particles acidic can land on buildings and damage their surfaces. Hydrogen chloride (Hcl) is carried in the air through an industrial source like combustion of fuels, refuse incineration etc, if released to soil, it will usually quickly react with alkaline and other buffering components, if present. It can be mobile in soil, however, and may contaminate groundwater (Reports by United States Environmental Protection Agency, US EPA). Also, harmful oxides derived from air pollution through burning of fossil fuel, gas, coal and oil which releases harmful gases such as; carbon dioxide, nitrogen oxides, sulphur oxide and tiny solid particles into the atmosphere (Abba, 2017). The main aim of this experimentation is to study the effect of partial replacement of cement by metakaolin on the durability property of stabilized laterite bricks when subjected to Hcl and H_2SO_4 acids.

2.0 **MATERIALS AND METHODS**

2.1 Research Materials

The materials that were used in this research include; laterite, metakaolin, cement, water, used engine oil, hydrochloric (Hcl) and sulfuric (H_2SO_4) acid solutions.

2.1.1 Laterite

The laterite sample was collected from an open barrow pit at Gumsuri Village of Dambo'a Local Government Area of Borno State, Nigeria. Upon visual examination was free of tree roots, debris, organic materials and upon transporting to the laboratory, it was air-dried for 24 hrs period and pulverized and bagged for use in accordance with BS EN 12620 (2002).

2.1.2 Metakaolin

The kaolin used to produce the metakaolin was obtained locally from Alkaleri Local Government Area of Bauchi State and heated to a temperature of about 700^0 C in a kiln at the industrial design department

Abubakar Tafawa Balewa University, Bauchi. The physical properties and oxide composition of metakaolin were checked and found suitable for this study.

2.1.3 Portland Cement

Portland cement (PC) Ashaka cement brand of 50kg by weight and which was conformed to BS EN 197-1: (2011) and was bought from a retail outlet.

2.1.4 Hydrochloric Acid (Hcl) and Sulfuric Acid (H_2SO_4) Solutions

2.5 Molar concentrations of each acids were used.

2.2 Methods

The methods used in this research work to achieve the set aim and objectives are preliminary tests for the identification and classification of laterite and metakaolin as well the primary tests in determining the mechanical properties (dry and wet compressive strengths, flexural strength, abrasion resistance) and water absorption on the hardened specimens of the control and varying percentages of MK replacements (Composite Specimens).

2.2.1 Preliminary Laboratory Tests on Laterite and MK

Sedimentation test was carried out for the laterite identification and classification and X- ray diffraction (XRD) & X-ray fluorescence (XRF) were carried out on both MK and laterite to determine their mineralogical compositions for the preparation of laterite bricks stabilized with cement and MK.

i. Specific gravity (according to BS 1377, 1975)
ii. Bulk density (according to BS 812, part 2: 1995)
iii. Particle size distribution (according to BS 1377, 1995)
iv. Atterberg limits (according to 1377, BS 1975)
v. Moisture content (according to 1377, BS 1975)
vi. Fineness modulus (according to ASTM, C136)

III **EXPERIMENTAL DESIGN**

3.1

	Mix Ratio (%)					
	L	PC	MK			
A	85	15	0	93.528	16.524	0
B	85	12.5	2.5	93.528	13.752	2.736
C	85	10	5	93.528	11.016	5.508
D	85	7.5	7.5	93.528	8.244	8.244
E	85	5	10	93.528	5.508	11.016
F	85	2.5	12.5	93.528	2.736	13.752
G	85	0	15	93.528	0	16.524

Specimens preparation: Describes the raw materials used, the mix proportion, method of production used, curing period and dimension of the specimens. The respective quantities of laterite, MK, Portland cement and the water required for the mixes were measured in litres.

i.Mix proportion: the batching method employed in this work was carried out by equivalent weight of mass of the constituent materials (laterite, MK, PC, and water) were obtained by weighing the mass of equal volume of each component constituent materials. The mixes were conducted to study the variations in dry compressive strength, wet compressive strength, flexural strength abrasion resistance and water absorption of the bricks produced control (0% MK) and composite specimens. The laterite contents in each aggregate mix were partially replaced with MK at 2.5%, 5%, 7.5%, 10%, 12.5% and 15% of the laterite volume which resulted to seven mix ratios and stabilized with Portland cement. Each seven mix ratios were mixed with same water-cement ratio of 0.5 which produced a total of seven (7) proposed design mix ratios.

Table 1: Batching of Materials

ii. Sample Preparation: the laterite was properly air dried for three (3) days before use. The mix proportions were measured by weights and a total of two hundred and eighty-eight (288) bricks were produced. Trial mixes were done to determine the idle water content for the experiment 50% of the equivalent mass of Portland cement gave satisfactory results and hence adopted. Laterite and MK were mixed together and cement was added to the mixture. Thereafter, water was added based on the water-cement ratio and mixing continued until a homogenous mix was obtained. A rectangular open wooden moulds were fabricated using marine boards for easy removal placement of the freshly cast bricks and demoulding oil were applied to the moulds inner faces. The bricks were cast in an open wooden moulds on a clean weather tied polythene under a semi-permanent shade and equally covered with same quality of polythene for curing. The curing of the composite specimens was done by wetting the bricks by sprinkling a dilute of Hcl and H_2SO_4 independently at seven (7) days intervals for twenty-eight (28) days.

3.2 Tests of mechanical properties on hardened specimens

3.2.1 Dry compressive strength

3.2.2 Wet compressive strength

3.2.3 Flexural strength

3.2.4 Abrasion resistance

3.2.5 Water absorption

3.0 RESULTS AND DISCUSSION

3.1 Results Presentation

3.1.1 Physical and Chemical Properties of Laterite, Metakaolin and Ashaka Cement

Table 2: Properties of Laterite Soil.

Physical Properties	Values Physical Properties
Colour	Reddish-brown
Condition of sample	Oven-dried
Specific gravity (GS)	3.10
Natural moisture content	
Plastic limit (%)	17
Liquid limit (%)	32
Coarse silt-fraction (%)	4.6
Clay	24.8
Fine silt	20.6
Medium silt	28.4
Coefficient of uniformity, Cu	27.6
Coefficient of curvature, Cc	0
Plasticity index, PI (%)	15
Plasiticity dry unit weight max. (Kg/m3)	1900
Optimum moisture content, OMC (%)	9.5
AASHTO Classification system	A-2-6
Bulk density (kg/m^3)	2023

Table 3: Chemical Properties of the Laterite Sample

Elements	Oxides	Compositions (%)
Al	Al2o3	10
Si	SiO2	41.7
P	P2O5	0.50
K	K2O	1.50
Ca	CaO	0.720
Sc	Sc2O3	0.005
Ti	TiO2	1.89
V	V2O5	0.12
Cr	Cr2O3	0.14
Mn	MnO	0.21
Fe	FeO3	41.54
Ni	NiO	0.050
Cu	CuO	0.072
Rb	Rb2O	0.19
Zr	ZrO2	1.1
Ba	BaO	0.18
Total		99.85

Table 4: Physical Properties of Metakaolin

Physical form	Powder
Colour	Off-white, Gray
Specific Gravity, Gs	2.40 to 2.60
Fineness	8000 to 15000kg/m2

Table 5**:** Chemical Composition /Oxides of Metakaolin XRF Test at 960^{0}C

Oxide	%Composition
$Si0_2$	42.46%
Al_20_3	38.98%
$Fe\ 0_3$	0.80%
Na0	0.04%
K20	0.02%
$Ti0_2$	1.32%
Ca0	5.83%
Mn0	1.20%
Loi	8.95%

Table 6: Chemical Properties of Ashaka cement

Oxide	Weight (%)	limits Specified by (BS 12 1989)
Sio2	19.68	17-25
Fe 03	6.44	3-8

Al2 O3	3.32	0.5-6.0
CaO	60.92	60-67
MgO	0.97	0.1-4.0
SoO	2.28	1-3
NaO	0.12	
K2O	0.85	

Table 7: Physical Properties of Ashaka Cement

Oxide	Weight (%)	limits Specified by (BS 12 1989)
Specific Gravity (Gs)	3.15	
Fineness (kg/m^2)	370	275
Loss on igmition	1.0	1.2
Soundress	2	10

Table 8: Acidity Tests of Hcl and H_2SO_4

Volume of concentration used (%)	2.5%	2.5%
Acids	Hcl	H_2SO_4
pH value	1.8	1.8
Remark	Acidic	Acidic

3.2 Mechanical properties test results on hardened specimens

3..2.1 Dry compressive strength

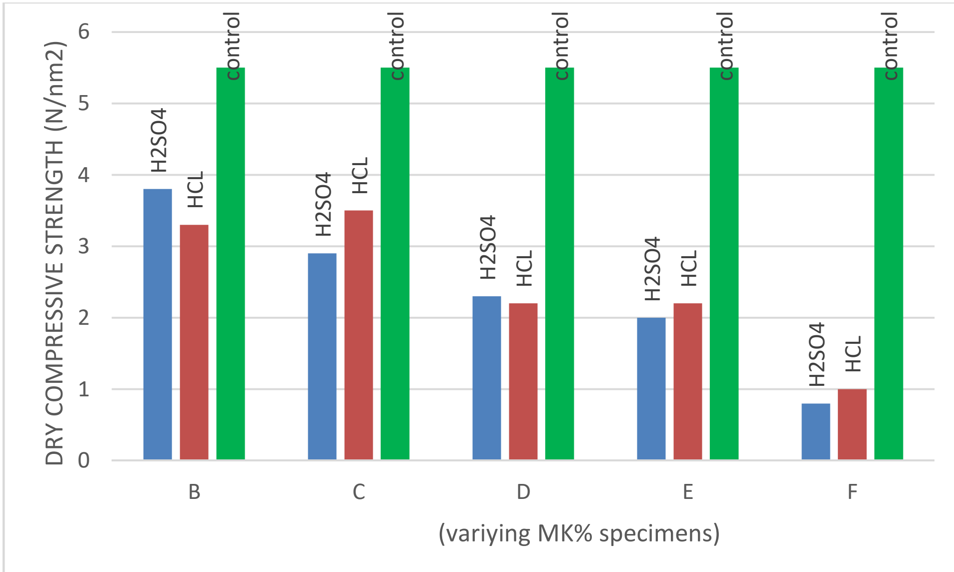

Figure 1: The relationship between dry compressive strength of composite specimens at 28 days

The highness in compressive strength exhibited by the control specimens could be due to higher cement content increased adequate bonding of laterite which could as well increased the density. However, higher cement content results in increased water absorption rates. The appreciable minimum strengths requirement recorded with mix set E due to the fact that MK used for this research contained a very significant percentages of SiO_2, Al_2O_3 and appreciable percent of CaO which were about 42.46%, 38.39% and 5.83% respectively had no doubt played vital role in developing and increasing the strength properties. Mix set G (15%MK + 0%PC) had not hardened even as at 28 days of curing and therefore, no tests were performed on these specimens. This indicates that laterite mixed with MK and water requires a minimum of 5% PC to enable setting of specimens after production. However, the results obtained in this research from mix set E were conformed to the minimum strength recommended by the Nigerian Building and Road Research Institute (NBRRI).

3.2.2 Wet compressive strength

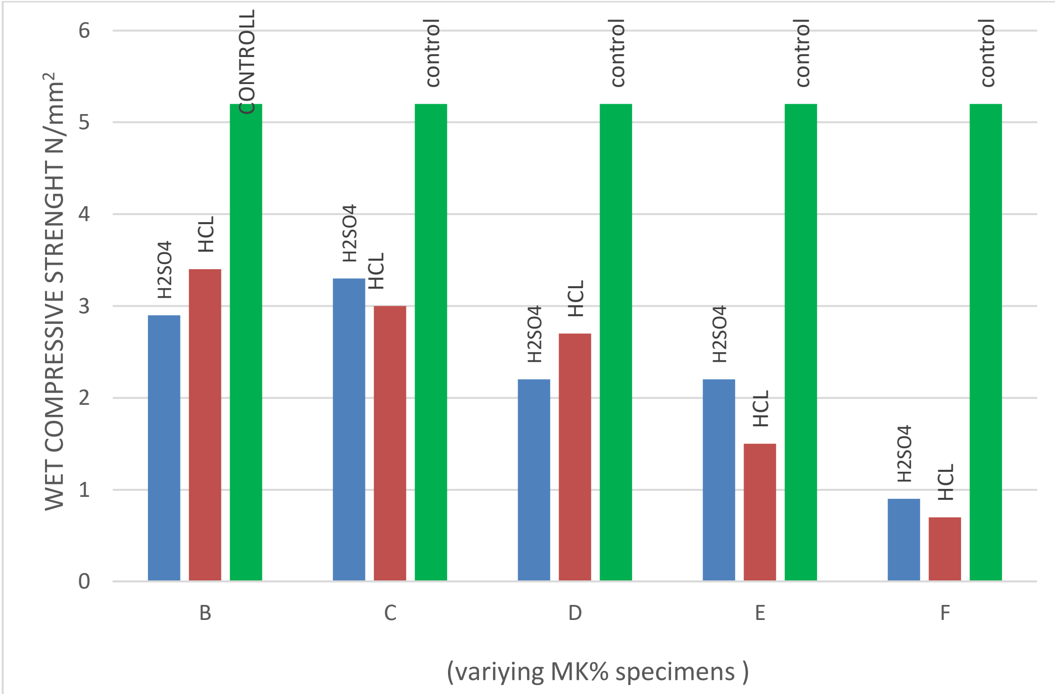

Figure 2: The relationship between wet compressive strength of composite specimens at 28 days

The behaviors of variation of decreased in wet compressive strength loss in which mix set F extremely affected by the acidic environments with the loss in strength of (81.0% in HCl and 82.4% in H_2SO_4) respectively. The range of compressive strength obtained in both environments from 0.996 to 3.4N/mm^2 in Hcl and 0.9 to 2.9N/mm^2 in H_2SO_4 with 5.2N/mm^2 as the control strength which were agreed in excess to what was obtained by Raheem *et al.,* (2012) from 0.43 to 1.69 N/mm^2 at cement replacement rate from 0 to 15%. However, both results met the minimum requirement recommended by the Nigerian Industrial Standard, NIS (2006).

3.2.3 Flexural strength

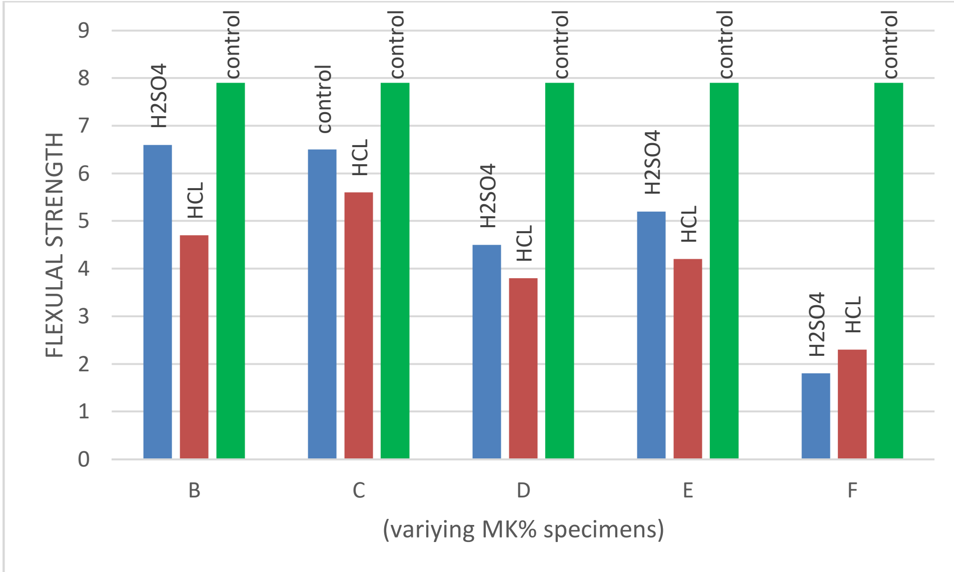

Figure 3: The relationship between average flexural strength and composite specimens at 28 days of curing

As Figure 3: shown the flexural strength obtained was the highest among all strengths tested on the laterite bricks, though. Wet compressive strengths exhibited same decreased trend in strengths. Mixes set B and C recorded least acidic effects with slight decreased compared to E above as thus, B (40.2% in Hcl & 17.5% in H_2SO_4) and C (29.9% in Hcl & 18.8% in H_2SO_4) environments respectively. The results obtained were not agreement with what was obtained 8.2 N/mm^2 at 28 days by Salifu *et al*., (2018) and as well that of control specimens as counterpath. This could also be due to aggressive acids effects accompanied in the curing environments.

3.2.4 Abrasion resistance

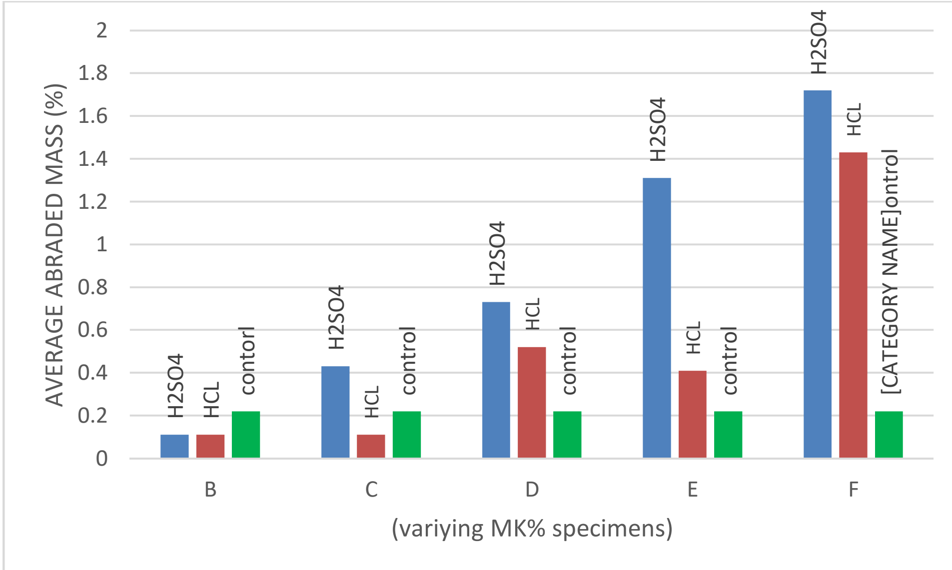

Figure 4: The abrasion resistance of the composite specimens at 28 days

Figure 4 indicated clearly that the abrasion resistance of laterite bricks increases with increasing in MK and decreasing PC. Specimen F recorded the highest abraded mass loss with an average of (1.43%) in Hcl and (1.72%) in H_2SO_4 and was considered most affected by both acidic environments but, however, higher abrasive coefficients indicates higher strength bond between particles whereas, specimens exhibited lower coefficients showed weaker bond.The rate of abrasion resistance index obtained 0.11 to 1.72% was slightly lower than with the findings of Olowu *et al.*, (2014) ranges from 1 to 2% and higher than 0.35 to 1.26 % obtained by Raheem *et al.,* (2012) which could be as a result of difference methods of stabilization adopted and as well the curing method.

3.2.5 Water absorption

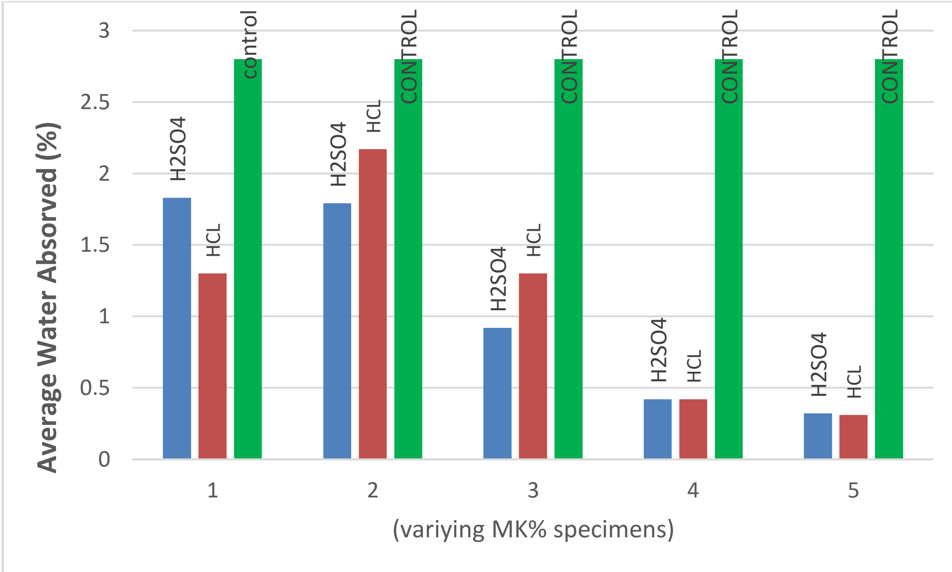

Figure 5: The relationship between Average water absorption and MK%

Figure 5 recorded a contrary trend of decreased pattern against abrasive resistance test results, it was observed that the water absorption rate is inversely proportional to MK content i.e., as MK content increased, the absorption rate decreased with decreased in cement content in both acidic environments. This phenomenon could be attributed to the decreasing volume of voids which have been filled with the MK particles and therefore, minimized the permeability of the specimens. Since, the trend of decrease is common to all various replacement levels. The results of water absorption test obtained from this research 0.31 to 1.83% was far below compared to the findings of Balaji *et al*., (2020) 8.9 to 13.7% and that obtained by Raheem *et al.,* (2012) from 2.90 to 1.26%. However, the results obtained in this research had met both the permissible water absorption according to BIS specification and NIS (2004).

4.0 CONCLUSIONS AND RECOMMENDATION

Based on the summary of this research, the following conclusions were drawn,

a. MK used found to had significant amounts of SiO_2, Al_2O_3, FeO_3 and CaO which were an active oxides of Ashaka cement had play a vital role in developing and increasing the strengths properties as these oxides could react $Ca(OH)_2$ in cement to secondary calcium silicate hydrate and calcium sulphoaluminate hydrates made it chemically stable and structurally dense by reducing the number of micro pores of the specimens as in case of water absorption property. Therefore, MK was recommended to be used as a viable alternative to the use of cement as a form of stabilizer for laterite bricks production.

b. The composite specimens of both acidic environments had maintained their appearance (had no trace of cracks due to drying shrinkage). However, the specimens had loss dry compressive strength, wet compressive strengths, flexural strengths, abrasion resistance. Therefore, not recommended to be used in an acidic environment like Hcl and H_2SO_4.

c. The performance of specimen E mix set (10%MK + 5%PC) was found to be optimum proportion. Therefore, recommended for practical application in terms of characteristic strengths, abrasion resistance and water absorption properties.

APPENDIX

The Brazilian silica/sesquioxide (S/R) has been used for the classification of the soil as laterite as thus;The silica/sesquioxide ratio S/R in calculated as follows: (DNER-ME 030/94) 2 for laterite

$$\frac{S}{R} = \frac{Si02}{60}$$

$$\frac{Al203}{102} + \frac{Fe02}{160} = \frac{41.7}{60}$$

$$\frac{10}{102} + \frac{41.54}{160}$$

$$\frac{0.695}{0.09804+0.25963}$$

$$\frac{0.695}{0.358}$$

$$= 1.94$$

$$\frac{S}{R} = 2$$

Where; from table 3

Si 02 = 41.7%

Al2 03 = 10%

Fe 02 = 41.54%

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Abbreviation

BS 1377 (1975)- Methods of test for soil for civil engineering purpose (British Standard).

BS 812 PART 2: (1995) Testing aggregates methods determination of density.

ASTM C136- Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates.

BS EN-772-1(2011) Methods of test for masonry units.

ASTM C67-07 (2007) Standard Test Methods for Sampling and testing Structural Clay Tile.

BS 1881: PART 122 (2011) Testing concrete Method for determination of water absorption.

BS 812-110: (1990)-Testing aggregates Methods for determination of aggregate crushing value (ACV)

(DNER-ME 030/94) Brazilian Method of Determining laterite Soils

AASHTO- American Association of State highway Transportion Officials. Standard Organistion