Model for Prediction of the Quantity of Absorbed Water In Clay Materials Exposed To Hot-Humid Environment

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Abstract: Model for prediction of the quantity of absorbed water in clay materials exposed to hot-humid environment has been derived. These clay materials were prepared using different grain sizes; <100μm, 100-300μm, 300-1000 μm and their respective mixtures. The derived model;

$$\beta = \left(\frac{\gamma}{\left(\alpha\,(S)^{0.995} \right)} \right)$$

was found to be dependent on the bulk density, apparent porosity and the shrinkage sustained on the clay body at any point in time under the hot-humid condition. The validity of the model is rooted on the expression; $S = (\gamma/\alpha\beta)^{1.005}$ where both sides of the expression are correspondingly almost equal. The maximum deviation of the model-predicted quantity of absorbed water from the corresponding experimental values is 8% which is within the acceptable range of deviation limit for experimental results.[Researcher. 2009;1(6):33-37]. (ISSN: 1553-9865).

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1. Introduction

Following studies by Reed (1988), firing of clay was found to proceed in three stages; preliminary reactions which include binder burnout, elimination of gaseous product of decomposition and oxidation, sintering as well as cooling which may include thermal and chemical annealing. Barsoum (1997),Viewey and Larrly (1978) and Keey (1978) have studied the shrinkage of clay during drying. In all these works, porosity has been shown to influence the swelling and shrinkage behaviour of clay products of different geometry. Reed (1988) reported that drying occurs in three stages; increasing rate, constant and decreasing rate. He pointed out that during the increasing rate; evaporation rate is higher than evaporating surface hence more water is lost. At constant rate, the evaporation rate and evaporation surface are constant. The researcher posited that shrinkage occurs at this stage. In a similar study, Keey (1978) suggested that at this stage, free water is removed between the particles and the inter-particle separation decreases, resulting in shrinkage. During the decreasing rate, particles make contacts as water is removed, which causes shrinkage to cease.

Model for calculating the volume shrinkage resulting from the initial air-drying of wet clay has been derived by Nwoye (2008). The model;

$$\theta = \gamma^3 - 3\gamma^2 + 3\gamma \qquad (1)$$

calculates the volume shrinkage when the value of dried shrinkage γ, experienced during air-drying of wet clays is known. The model was found to be third-order polynomial in nature. Olokoro clay was found to have the highest shrinkage during the air drying condition, followed by Ukpor clay while Otamiri clay has the lowest shrinkage. Volume shrinkage was discovered to increase with increase in dried shrinkage until maximum volume shrinkage was reached, hence a direct relationship.

Nwoye et al.,(2008) derived a model for the evaluation of overall volume shrinkage in molded clay products (from initial air-drying stage to completion of firing at a temperature of 1200^0C). It was observed that the overall volume shrinkage values predicted by the model were in agreement with those calculated using conventional equations. The model;

$$S_T = \alpha^3+\gamma^3-3(\alpha^2+\gamma^2)+3(\alpha+\gamma) \qquad (2)$$

depends on direct values of the dried γ and fired shrinkage α for its precision. Overall volume shrinkage was found to increase with increase in dried and fired shrinkages until overall volume shrinkage reaches maximum.

Successful derivation of a model for calculating the quantity of water lost by evaporation during oven drying of clay at 90^0C has been carried out (Nwoye,2009). The model;

$$\gamma = \exp[(\ln t)^{1.0638} - 2.9206] \quad (3)$$

indicated that the quantity of evaporated water, γ during the drying process is dependent on the drying time t, the evaporating surface being constant. The validity of the model was found to be rooted in the expression $(\text{Log}\beta + \ln\gamma)^N = \ln t$.

Model for predictive analysis of the quantity of water evaporated during the primary-stage processing of a bioceramic material sourced from kaolin has been successfully derived (Nwoye et al.,2009a) .The model;

$$\alpha = e^{(\ln t/2.1992)} \quad (4)$$

indicates that the quantity of water α, evaporated at 110^0C, during the drying process is also dependent on the drying time t, where the evaporating surface is constant. It was found that the validity of the model is rooted on the expression $(\ln t/\ln\alpha)^N = \text{Log}\beta$ where both sides of the expression are correspondingly approximately equal to 3. The respective deviation of the model-predicted quantity of evaporated water from the corresponding experimental value was found to be less than 22% which is quite within the acceptable deviation range of experimental results.

Nwoye et al. (2009b) derived a model for quantifying the extent and magnitude of water evaporated during time dependent drying of clay. The model;

$$\gamma = \exp((\ln t/2.9206)^{1.4}) \quad (5)$$

indicates that the quantity of evaporated water γ during the drying process (at 90^0C) is dependent on the drying time, t the evaporating surface being constant. It was found that the validity of the model is rooted in the expression $\ln\gamma = (\ln t/\text{Log}\beta)^N$ where both sides of the expression are correspondingly almost equal.

The present work is to derive a model for prediction of the quantity of absorbed water by Otamiri clay materials exposed to hot-humid environment.

2. Materials and Methods

2.1. Model Formulation

Results of the experiment previously carried out (Nwoye,2006) were used for the model derivation. These results as shown in Table 1 indicate that;

$$S = \left(\frac{\gamma}{\alpha\beta}\right)^N \quad \text{(approximately)} \quad (6)$$

Introduction of the value of N to equation (6) reduced it to;

$$S = \left(\frac{\gamma}{\alpha\beta}\right)^{1.005} \quad (7)$$

Dividing the indices of both sides of equation (7) by 1.005 reduces it to;

$$S^{1/1.005} = \left(\frac{\gamma}{\alpha\beta}\right) \quad (8)$$

$$(S)^{0.995} = \left(\frac{\gamma}{\alpha\beta}\right) \quad (9)$$

$$\beta = \left(\frac{\gamma}{\alpha\left(S\right)^{0.995}}\right) \quad (10)$$

Where

N = 1.005; Coefficient of shrinkage Otamiri clay at 1200^0C (determined in the experiment (Nwoye,2006)

(γ) = Bulk density of the clay body in the hot-humid environment (g/cm^2)

(α) = Fractional value of apparent porosity of the clay body in the hot-humid environment

(β)= Fractional value of water absorbed by the clay body under the hot-humid environment

Equation (10) is the derived model

3. Boundary and Initial Conditions

Consider a rectangular shaped clay product of length 70mm, width 17mm, and breadth 9mm exposed to drying in the furnace while it was in wet condition. Initially, atmospheric levels of oxygen are assumed. Atmospheric pressure was assumed to be acting on the clay samples during the drying process (since the furnace is not air-tight). The grain sizes for the clay materials used are, <100μm, 100-300μm, 300-1000μm and their respective mixtures. The hot-humid environment was at a temperature; 1200^0C, and the resident time of clay bodies under the environment; 18hrs. The boundary conditions are: atmospheric levels of oxygen at the top and bottom of the clay samples since they are dried under the atmospheric condition. No external force due to compression or tension was applied to the drying clays. The sides of the particles and the rectangular shaped clay products are taken to be symmetries.

4. Model Validation

The formulated model was validated by direct analysis and comparison of the model-predicted β values and those from the experiment (Nwoye,2006) for equality or near equality.

Analysis and comparison between these β values reveal deviations of model-predicted β from those of the experimental values. This is believed to be due to the fact that the surface properties of the clay and the physiochemical interactions between the clay and binder, which were expected to have played vital role

during the evaporation of water were not considered during the model formulation. This necessitated the introduction of correction factor, to bring the model-predicted β value to that of the corresponding experimental value.

Deviation (Dv) (%) of model-predicted values of β from the experimental values is given by

$$Dv = \left(\frac{\beta_M - \beta_{exp}}{\beta_{exp}} \right) \times 100 \qquad (11)$$

Correction factor (Cf) is the negative of the deviation i.e

$$Cf = -Dv \qquad (12)$$

Therefore

$$Cf = -100 \left(\frac{\beta_M - \beta_{exp}}{\beta_{exp}} \right) \qquad (13)$$

Introduction of the value of Cf from equation (13) into the model gives exactly the corresponding experimental value β_{exp}.

5. Results and discussions

The model is equation (10). It was found that the model is dependent on the bulk density, apparent porosity and the shrinkage sustained on the clay body at any point in time under the hot-humid condition. The validity of the model was found to be rooted on the expression; $S = (\gamma/\alpha\beta)^{1.005}$ where both sides of the expression are correspondingly almost equal. Table 2 also agrees with equation (6) following comparison of the value S and that of $(\gamma/\alpha\beta)^{1.005}$ evaluated from Table 1 as a result of corresponding computational analysis. Fig. 1 shows appreciable close alignment of the curves from model-predicted values of absorbed water (βmod) and that from the corresponding experimental values (βexp). It is strongly believed that the degree of alignment of these curves is indicative of the proximate agreement between both experimental and model-predicted quantities of absorbed water by the clay material. Table 3 shows that the maximum deviation of the model-predicted quantity of absorbed water from the corresponding experimental values is less than 8% which is within the acceptable range of deviation limit for experimental results.

The model can be useful to engineers for carrying out failure or survival analysis of clay materials (exposed to hot-humid environment while in service) relative to the varied clay porosity, water absorption, bulk density and shrinkage sustained in the clay bodies under this service environment. This is because swelling of clay materials is likely when water absorbed by the materials becomes excessive. Nwoye (in press) found that swelling process weakens the grain boundaries and also loosen the clay-binder interface leading to collapse of the microstructure of the clay material. This implies failure.

Conclusion

The model computes the quantity of absorbed water in clay materials exposed to hot-humid environment. The model is dependent on the bulk density, apparent porosity and the shrinkage sustained on the clay body at any point in time under the hot-humid condition. The validity of the model is rooted on the expression; $S = (\gamma/\alpha\beta)^{1.005}$ where both sides of the expression are correspondingly almost equal. The maximum deviation of the model-predicted quantity of absorbed water from the corresponding experimental values is less than 8% which is within the acceptable range of deviation limit for experimental results.

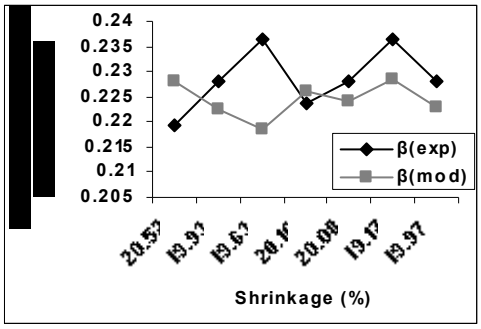

Fig.1: Comparison of the quantities of water absorbed by the clay body under the hot-humid environment as obtained from experiment (Nwoye,2006) and derived model.

Table1: Variation of apparent porosity, water absorption, bulk density and volume shrinkage with grain size of Otamiri clay body exposed to hot-humid environment.(Nwoye,2006)

$(\gamma/\alpha\beta)$	$(\gamma/\alpha\beta)^{1.005}$	S (%)
21.0364	21.3593	20.52
19.1634	19.4484	19.93
17.8518	18.1109	19.63
20.0678	20.3710	20.16
19.4604	19.7514	20.08
18.2583	18.5254	19.17
19.2456	19.5323	19.97

Table 2: Variation of $(\gamma/\alpha\beta)^{1.005}$ with S

Dv (%)	Cf (%)
+4.06	-4.06
-2.41	+2.41
-7.69	+7.69
+1.03	-1.03
-1.62	+1.62
-3.34	+3.34
-2.19	+2.19

Table 3: Deviations (from experimental values) of model-predicted volume shrinkage and the associated correction factors

Grain size (μm)	α	β	γ	S (%)
(A) <100	0.2559	0.2192	1.18	20.52
(B) 100-300	0.2608	0.2281	1.14	19.93
(C) 300-1000	0.2628	0.2366	1.11	19.63
A + B	0.2584	0.2237	1.16	20.16
A + C	0.2593	0.2279	1.15	20.08
B +C	0.2618	0.2364	1.13	19.17
A + B + C	0.2598	0.2280	1.14	19.97

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