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Relative Humidity Period Influence on Drying Induced Stresses in Intermittent Drying of Clay

M. Heydari, K. Khalili, S. Y. Ahmadi-Brooghani*

[1] Department of Engineering, University of Birjand, Birjand, Iran

ABSTRACT: Intermittent drying is an effective strategy for improving the drying kinetics, energy consumption as well as the quality of the dried products. The aim of this study is to investigate the effect of the period of intermittent drying on the drying kinetics and the induced stresses. To this end, a clay like material is used and by changing the air relative humidity periodically, the stresses induced were determined. Moisture, temperature and displacement are the main coupling variables of the drying equations set. Parameters variation with moisture and temperature are considered in modeling. Good agreement between experimental and simulation variables results reveals that the developed model is valid and accurate. Simulation results suggest that the drying rate should be kept at its minimum at the stage of disruption of hydraulic continuity. Due to the gradual disruption of capillary tubes in transition period, the part is affected gradually, and this necessitates the possible crack deformation points of the part to be sought simultaneously. Also, the current work studied the magnitude of each of stresses induced by non-uniform moisture distribution and stresses induced by non-uniform temperature distribution. It is shown that the thermal stresses are negligible compared to the moisture stresses and can be neglected in drying modeling.

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1- Introduction

Convective drying process in continuous conditions is easy to operate, but, it is not always efficient. Drying in continuous mild conditions induces smaller value stresses and long duration resulting better dried product quality, but higher energy consumption. Drying in continuous severe conditions, on the other hand, shortens the drying time but generates excessive stresses that may cause crack formation and makes dried products useless. Intermittent drying based on periodical changes of drying conditions can be one way to enhance the drying kinetic, quality of dried products and also improving the energy utilization. Surveying the literature reveals that, stresses induced by intermittent drying by periodically changing relative humidity has not been investigated. To deal with many restrictions found in literatures, a 3D numerical approach was used describe the drying process.

2- Methodology

2- 1- Mathematical modeling

One of the important aspects of modeling is providing an appropriate mathematical model. The particularity of the model developed is that the strong coupling between mass transport, heat transport and mechanical behavior of the material is taken into account. The equations which describe moisture, heat and mechanical aspects of drying are taken into account in the following form:

$$\frac{\partial w}{\partial t} = \nabla.\left(D \nabla w\right) \tag{1}$$

$$\rho C_p \frac{\partial T}{\partial t} = \nabla.\left(k \nabla T\right) \tag{2}$$

$$\nabla.\sigma = 0 \tag{3}$$

2- 2- Simulation

The numerical method used to solve this strongly coupled and nonlinear system was the finite element method. The heat and mass transfer equation and momentum equation were implemented in a finite element solver and solved simultaneously. The Arbitrary Lagrange-Eulerian (ALE) formulation was used. This allowed consideration of a drying process of a shrinking body, as is the case in the current study. The stresses induced by drying have been studied in three points of geometry presented in Fig.1.

2- 3- Model application to clay drying

The model validation was done by the comparison of the simulation and experimental results. The schematic of experimental equipment is presented in Fig. 2.

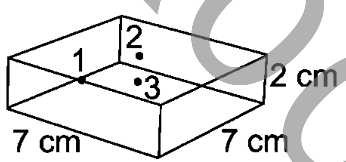

Fig. 1. Employed geometry in simulation

The drying process was controlled by a PC provided with the software and data acquisition card. The Kaolin was mixed with water to make a workable paste with approximately 33% (dry basis). The Cubic sample was dried at 100°C with a relative

Corresponding author, E-mail: s.y.ahmadi@birjand.ac.ir

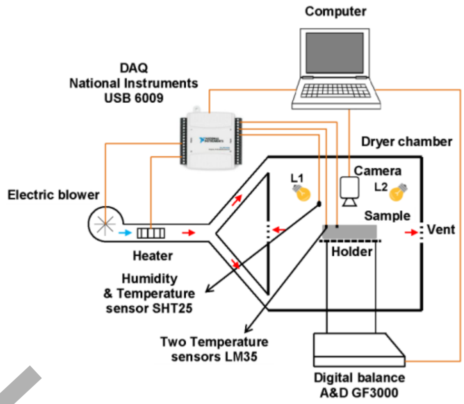

Fig. 2. Schematic of experimental setup

humidity of 10%. During the experimental run, snapshots of the sample shrinkage were taken every 10s. Volumetric shrinkage of the sample was calculated using image processing techniques. Figs. 3 and 4 depicts the comparison between the experimental results and the simulated values of the mean moisture content and temperature of two surface points, respectively.

3- Results and Discussion

3- 1- Drying induced stresses

As a result of no-uniform shrinkage, stresses in dried sample remain [1]. The evolutions of the first principal drying induced stresses in three points illustrated in Fig. 1 are shown in Fig. 5.

3- 2- Intermittent drying

Intermittent drying simulated in constant temperature 100°C and changeable relative humidity between 10 and 30%. The

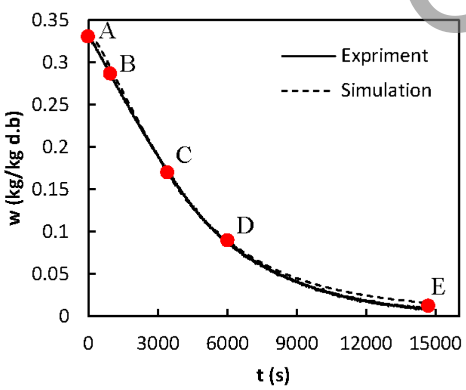

Fig. 3. Mean moisture content changes

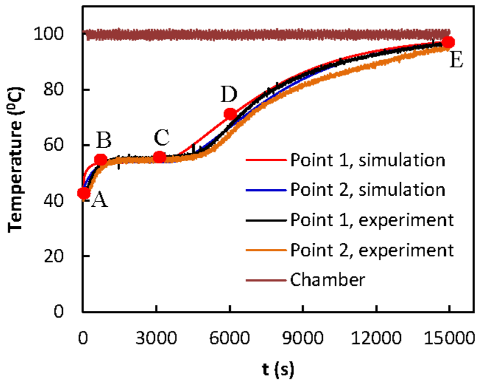

Fig. 4. Two surface points temperature changes

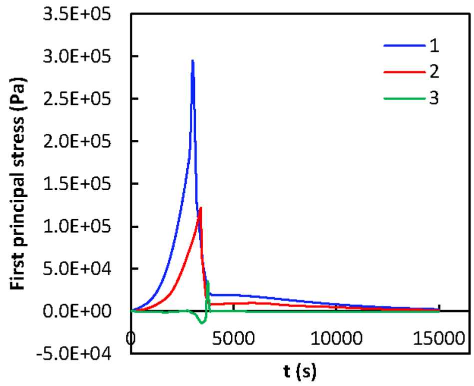

Fig. 5. First principal stress at 3 sample points

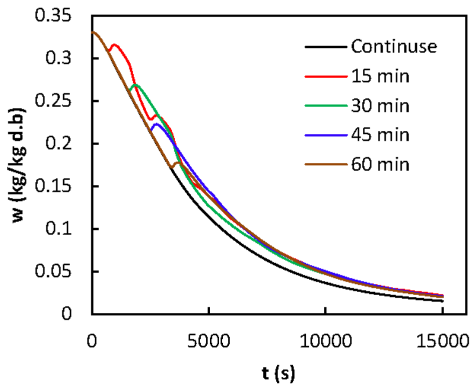

Fig. 6. Effect of drying air relative humidity period on the evolution of the mean temperature

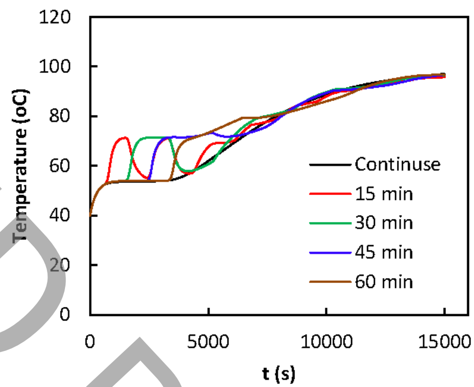

Fig. 7. Effect of drying air relative humidity period on the evolution of the mean moisture

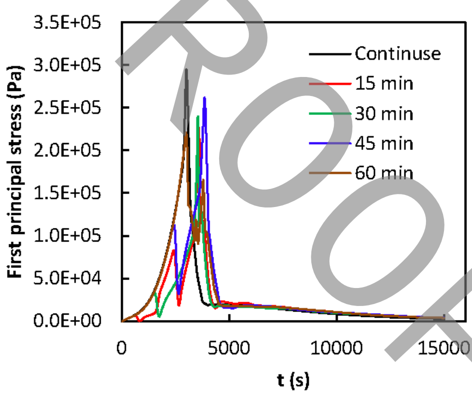

Fig. 8. Effect of drying air relative humidity period on the evolution of the first principal stress

period of relative humidity changes amounted to 15, 30, 45, 60 min. the mean moisture content and temperature evolutions of the sample are shown in Figs. 6 and 7, respectively.

The evolution of first principal stress at point 1 the location of maximum stress at intermittent and continues state are shown in Fig. 8. The maximum stress value increases in the intermittent drying at period of 60, 15, 30 and 45 min, respectively.

4- Conclusions

A 3D fully coupled model was developed to predict the stress–strain and clay–water characteristics response to drying process. Good agreement between experimental and simulation variables results such as moisture, temperature, volumetric strain and density reveals the validity and accuracy of the developed model, modeling moisture, heat and mechanical aspects of drying process. The findings of the current study suggest that the intermittent drying accomplished through periodically changing air relative humidity is a solution to reduce the stresses induced by drying to avoid cracking of dried products. The period of periodic change of the air relative humidity influences the maximum stress value depending on the material properties and sample dimensions. Hence inappropriate design of intermittent drying scheme may increase stresses value and decrease the quality of dried product.

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