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HEAT AND MOISTURE TRANSFER, DEFORMATION AND STRESS ANALYSIS DURING DRYING OF CERAMIC BRICKS

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ABSTRACT

Drying is a simultaneous phenomenon of heat and mass transfer and deformations that take places in porous bodies, like clay. Many researchers have reported drying of clay [1]-[3]. During the drying of solid, the shrinkage phenomenon exists, and it alters the drying kinetics and the dimensions of the solid. Depending on the drying conditions, structures of the material and geometry of the product, the shrinkage phenomenon can cause nonsymmetrical and stress that provoke cracks and fracture inside the solid. The objective of this work is to study heat and mass transfer in parallelepiped solids including shrinkage and hygrothermal stress analysis and to apply the methodology to describe drying of ceramic materials (clay bricks) (Figure 1).

Heat conduction and mass diffusion modeling was used as follows: $\partial(\zeta\Phi)/\partial t=\partial(\Gamma^{\Phi}\partial\Phi/\partial x)/\partial x+\partial(\Gamma^{\Phi}\partial\Phi/\partial y)/\partial y+\partial(\Gamma^{\Phi}\partial\Phi/\partial z)/\partial z$, where for heat transfer $\Gamma^{\Phi}=k$, $\zeta=\rho c_p$, $h=h_c$ and $\Phi=\theta$, and $\Gamma^{\Phi}=\rho D$, $\zeta=\rho$, $h=h_m$ and $\Phi=M$ for mass transport. The uniform initial, symmetry and convective boundary conditions were used. The average temperature and average moisture content were calculated by classical mode. The following shrinkage model was utilized to obtain the changes of volume in each time during the drying process: $V_t = V_o[1-\beta(M_o-\bar{M})]$. The hygrothermoelastic stresses was calculated by applying the usual principles of continuum mechanics assuming the behavior of the solid to be elastic as follows [4]: $\sigma=E(e-\gamma\Delta\theta-\beta\Delta M)+\sigma_o$. The normal stress (shear stress was neglected) was obtained as follows: $(-\alpha_{\theta x}\Delta\theta-\alpha_{Mx}\Delta M)\,E = [\sigma_x-\nu(\sigma_y+\sigma_z)]$; $(-\alpha_{\theta y}\Delta\theta-\alpha_{My}\Delta M)E=[\sigma_y-\nu(\sigma_x+\sigma_z)]$; $(-\alpha_{\theta z}\Delta\theta-\alpha_{Mz}\Delta M)E=[\sigma_z-\nu(\sigma_x+\sigma_y)]$.

In this work we use the finite-volume method to discretize the governing equations [5]. The set of equations is solved iteratively using the Gauss-Seidel method and stopped when convergence criterion was found. The following data were used: $D=3.0\times10^{-8}$ m^2/s; $\alpha=k/\rho c_p=1.0\times10^{-7}$ m^2/s; $h_m=3.0\times10^{-6}$ m/s; $h_c=1.5$ W/m^{2}K; $\alpha_M=\beta/3=3.3\times10^{-2}$; $\alpha_\theta=\gamma/3=6.0\times10^{-6}$ ^{o}C^{-1}; $\theta_e=1.1\times10^{2}$ ^{o}C; $\theta_o=25$ ^{o}C; $M_o = 0.08$ (dry basis); $M_e= 2.0\times10^{-3}$ (dry basis); $\nu=0.35$; E = 70.0 MPa. To obtain the numerical results a computational code was implemented using the grid 20x20x20 nodal points and Δt=1s. These conditions were obtained by successive grid and time step refinements. Figure 2 shows the average

moisture content and average temperature of the brick during drying. We can see that the brick temperature it reach the equilibrium more fast than moisture content. Figures 3-6 illustrate the moisture content, temperature and normal stress distribution inside the solid obtained during drying. It is verified that highest moisture content, temperature and stress gradients occurs at the surface of the solid mainly in the vertex. So, this region is more susceptible to cracks, fissures and deformations that reduce quality of the bricks.

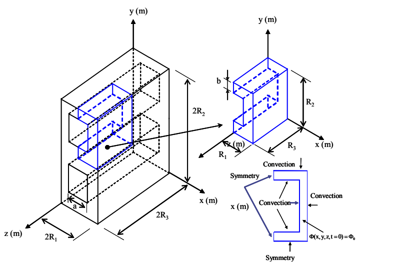

Figure 1- Scheme of the holed brick used in this study.

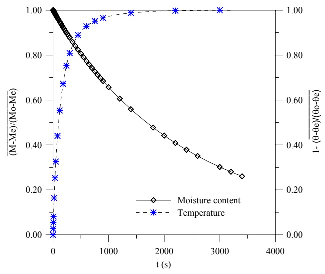

Figure 2 - Drying and heating kinetics of the solid.

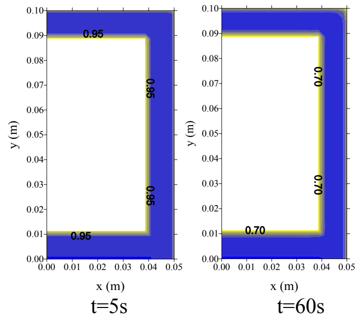

Figure 3 – (M-Me)/(Mo-Me) in z=0.05m (≅ R_3/2).

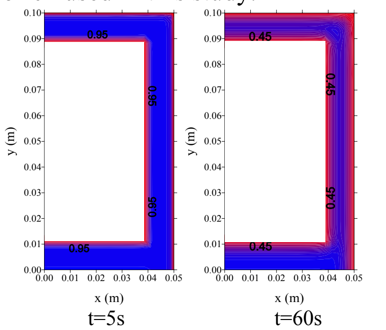

Figure 4 – (T-Te)/(To-Te) in z=0.05m (≅ R_3/2).

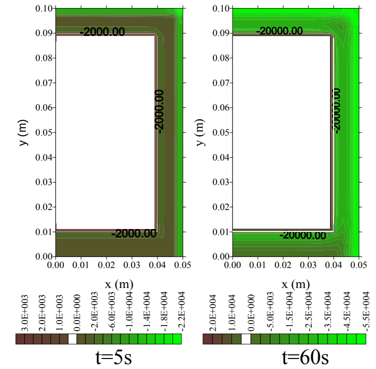

Figure 5 – Normal stress σ_z in z=0.05m (≅ R_3/2).

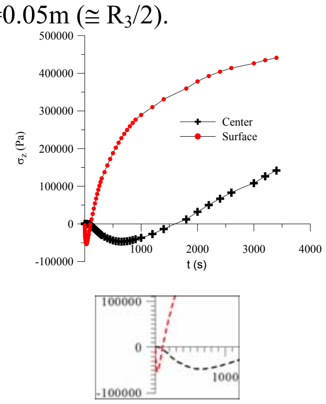

Figure 6 – Normal stress σ_z during the drying process.

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