

**MODELING OF CERAMIC BODIES DRYING AND
FIRING PROCESSES AND THEIR EFFECTS ON
PROPERTIES OF SINTERED CERAMIC BODIES**

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DECLARATION

I declare that this is my own work and this thesis/dissertation does not incorporate without acknowledgement any material previously submitted for a degree or diploma in any other University or Institute of higher learning and to the best of my knowledge and belief it does not contain any material previously published or written by another person except where the acknowledgement is made in the text. I retain the right to use this content in whole or part in future works (such as articles or books).

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DEDICATION

I would like to dedicate this thesis to my parents, husband, and daughter; without their cooperation and support, this study will not be completed; they are the very important part of the research.

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ABSTRACT

The ceramic tile industry is continuously exploring novel techniques to improve productivity while maintaining quality products. Optimization of drying and sintering steps of the ceramic tile manufacturing process can significantly enhance the productivity of the ceramic tile manufacturing industry. Thermal and mechanical stresses that occur within the ceramic body during the drying and sintering processes need to be precisely controlled to minimize defects and hence improve productivity. To optimize the drying process, the spatial variation of the moisture exchange rate within the ceramic tile body must be analyzed over time and kept below the critical moisture exchange rate. In the sintering process, controlling the quality of ceramic tiles depends on the spatial and temporal variations in linear shrinkage, MOR, and thermal stress throughout the sintering cycle. For an optimal sintering cycle, the thermal stress must remain below the MOR across both spatial and temporal dimensions. The existing kinetics models developed by previous researchers do not facilitate finding temporal and spatial changes in the moisture exchange rate, linear shrinkage, MOR, and thermal stress of the ceramic tiles, and it is difficult to optimize the drying and sintering processes. This investigation aimed to establish a robust numeric model for the drying and sintering processes of ceramic tile using computational fluid dynamics (CFD). The developed models are capable of predicting the moisture exchange rate, linear shrinkage, MOR, and thermal stress in ceramic tile during drying and sintering and optimizing each process. In this research, a Kaolin source named M2 Kaolin-based tile body composition was selected. The drying and sintering behaviors of ceramic tiles were investigated. Computational fluid dynamics (CFD)-based numerical models were developed separately for the drying and sintering processes for ceramic tiles. The drying model was used to evaluate the spatial variation of the moisture content in ceramic tiles and optimize the drying process of ceramic tiles for minimum drying time. The sintering model was used to assess the spatial and temporal variation in linear shrinkage, MOR, and thermal stress in the ceramic tile. The sintering process was optimized by accounting for thermal and mechanical stresses, ultimately determining the optimal sintering cycle where thermal stress remains below the modulus of rupture (MOR) throughout the ceramic body. To validate the ceramic tile drying and sintering models, the green body mixture of ceramic tile was prepared. Ceramic tiles were shaped by a powder pressing technique on a laboratory scale. The moisture variation of green ceramic tile with time was determined during the drying process. Dried tiles were sintered in a laboratory furnace by adjusting the maximum sintering temperatures. The structure of the green body mix and sintered ceramic tiles was analyzed. The linear shrinkage and modulus of rupture variation of each sintered tile were determined. Results developed by the simulated drying model were compared with data obtained by experiments conducted using green ceramic tiles. The results of the drying model for green ceramic tiles were validated and comply with the experiment results, and the R-squared value was 0.9. The CFD results regarding the moisture exchange rate of green ceramic tile with drying profiles were analyzed. It

confirmed that the optimum drying time was 60 minutes, and it was reduced by 76.2% of the time compared to the initial drying time. The developed drying model can be applied to optimize the local ceramic tile manufacturing process for improved productivity. The results obtained from the CFD model of the sintering process and the experimental outcomes of linear shrinkage and modulus of rupture were compared. The results of CFD simulation for the linear shrinkage and modulus of rupture of the tiles were validated and concurred with experimental outcomes, and the R-squared value of the results was 0.9. The CFD results regarding the thermal and mechanical stress of the ceramic tile body were analyzed, and it was confirmed that the optimum dynamic rate sintering cycle included 51.6 °C/min heating rate between 30-550 °C, 27.6 °C/min heating rate between 550-1200 °C, 57.0 °C/min cooling rate between 1200-1000 °C, and 19.8 °C/min cooling between 1000-30 °C. The optimum sintering time was 96 min, and the sintering time of the ceramic tile was reduced by 87.2% compared to the initial sintering profile. Hence, the developed CFD sintering model can predict the temporal and spatial changes in linear shrinkage and modulus of rupture of ceramic tiles through sintering without laboratory experimental effort. Therefore, the sintering model facilitates finding the exact sintering cycle associated with linear shrinkage and modulus of rupture. Finally, the quality of the ceramic tile is improved, and the drying and sintering times of ceramic tile are reduced. The developed CFD models for the drying and sintering processes enhanced the productivity of the ceramic tile, and the cost of production was reasonably lower.

Keywords: Ceramic Tile, Drying, Kaolin Clay, Numerical Modeling, Sintering

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LIST OF ABBREVIATIONS

Abbreviation	Description
CFD	Computer Fluid Dynamics
CM	Critical Moisture
CRP	Constant Rate Period
FRP	Falling Rate Period
DTA	Differential Thermal Analysis
TGA	Thermogravimetric Analysis
SEM	Scanning Electron Microscope
XRD	X-ray Diffraction Analysis
LOI	Loss on Ignition
MOR	Modulus of Rupture
EDXS	Energy Dispersive X-ray Spectroscopy
FDM	Finite Difference Method
FEM	Finite Element Method
FVM	Finite Volume Method
LBM	Lattice Boltzmann Method
SPH	Smoothed Particle Hydrodynamics
UDS	User Defined Subroutine
UDF	User Defined Function

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