Relating microstructural characteristics of fired clay to macroscopic material properties: a multiscale approach

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ABSTRACT

Pore-forming additives and temper have been used to improve the mechanical and thermal properties of fired clay since the very beginning of its fabrication [9], depending on its further use in pottery or as a building material. Nowadays, such pore-forming additives are used in brick production to reduce the bulk density of fired clay, thereby reducing the effective thermal conductivity [5] in order to minimize corresponding heat losses through building façades. However, material models able to describe the effect of such additives on the overall material behaviour with respect to thermal conductivity, stiffness and strength have not yet been in the scientific focus. This motivated the development of physically sound material models to improve present optimization concepts, which essentially rely on phenomenological observations until now.

Such material models, translating microstructural characteristics (such as porous space, morphology and the elastic and thermal properties of the constituent phases on a microscale) into corresponding material properties, are developed in the framework of continuum micromechanics or random homogenization theory [6, 7, 11], and were already successfully established for different materials, such as concrete [3, 10], wood [2, 8] or bone [1, 4]. A huge set of identification experiments to characterise the microstucture of the considered material is therefore needed, such as scanning electron microscopy coupled with energy dispersive X-rays and X-ray powder diffraction to identify the material phases and their morphology, μ-CT and mercury intrusion porosimetry to define the porous space, as well as nanoindentation and scanning thermal microscopy to determine elastic and thermal properties of the governing material phases.

With the derived information on the microstructural characteristics, a multiscale material model was developed, and results from the model were consequently compared to macroscopic measurements on a set of 12 different fired clays, allowing for a validation of the proposed model. The validated model is assumed to contribute to a comprehensive understanding of how microstructural characteristics affect the overall material behaviour, representing the basis for complete new optimizations stragies for fired clay products.

REFERENCES

[1] Abdalrahman, T., Scheiner, S., and Hellmich, C. (2015). Is trabecular bone permeability governed by molecular ordering-induced fluid viscosity gain? arguments from re-evaluation of experimental data in the framework of homogenization theory. *Journal of Theoretical Biology*, 365:433 – 444.

[2] Bader, T., Hofstetter, K., Hellmich, C., and Eberhardsteiner, J. (2010). Poromechanical scale transitions of failure stresses in wood: from the lignin to the spruce level. *ZAMM - Journal of Applied Mathematics and Mechanics / Zeitschrift für Angewandte Mathematik und Mechanik*, 90(10-11):750–767.

[3] Constantinides, G. and Ulm, F.-J. (2004). The effect of two types of c-s-h on the elasticity of cement-based materials: Results from nanoindentation and micromechanical modeling. *Cement and Concrete Research*, 34(1):67 – 80.

[4] Fritsch, A., Dormieux, L., Hellmich, C., and Sanahuja, J. (2009). Mechanical behavior of hydroxyapatite biomaterials: An experimentally validated micromechanical model for elasticity and strength. *Journal of Biomedical Materials Research Part A*, 88A(1):149–161.

[5] García Ten, J.a, Ten, J., Orts, M., Saburit, A. and Silva, G., (2010). Thermal conductivity of traditional ceramics. Part I: Influence of bulk density and firing temperature. *Ceramics International*, 36(6):1951–1959.

[6] Giraud, A., Gruescu, C., Do, D., Homand, F., and Kondo, D. (2007). Effective thermal conductivity of transversely isotropic media with arbitrary oriented ellipsoidal inhomogeneities. *International Journal of Solids and Structures*, 44(9):2627–2647.

[7] Hill, R. (1965). Continuum micro-mechanics of elastoplastic polycrystals. *Journal of the Mechanics and Physics of Solids*, 13(2):89 – 101.

[8] Hofstetter, K., Hellmich, C., and Eberhardsteiner, J. (2005). Development and experimental validation of a continuum micromechanics model for the elasticity of wood. *European Journal of Mechanics A/Solids*, 24(6):1030 – 1053.

[9] Kilikoglou, V., Vekinis, G. and Maniatis, Y. (1995). Toughening of ceramic earthenwares by quartz inclusions: an ancient art revisited. *Acta Metallurgica et Materialia*, 43:2959–2965.

[10] Pichler, B. and Hellmich, C. (2011). Upscaling quasi-brittle strength of cement paste and mortar: A multi-scale engineering mechanics model. *Cement and Concrete Research*, 41(5):467–476.

[11] Zaoui, A. (2002). Continuum micromechanics: Survey. *Journal of Engineering Mechanics (ASCE)*, 128(8):808–816.