A phenomenological model of starch expansion by extrusion

Magdalena Kristiawan, Guy G. Della Valle, Amadou Ndiaye, Bruno Vergnes, Chantal David

Poster for "Biobased composites & blends for structural materials"

A phenomenological model of starch expansion by extrusion

M. Kristiawan*[a], G. Della Valle[a], A. Ndiaye[b], B. Vergnes[c], C. David[d]

[a] *INRA, Biopolymers Interactions and Assemblies (BIA), Nantes, France*
[b] *INRA, Institut de Mécanique et d'Ingénierie (I2M), Université Bordeaux 1, Talence, France*
[c] *MINES ParisTech, CEMEF, Sophia-Antipolis Cedex, France*
[d] *Sciences Computers Consultants, Saint-Etienne, France*
* magdalena.kristiawan@nantes.inra.fr

The expansion phenomenon is a key-point of the development of extruded starch based composites. During extrusion, the molten material is forced through a die so that the sudden pressure drop causes part of the water to vaporize, giving an expanded cellular structure. The knowledge of the cellular structure is important because it impacts the mechanical properties of the foams, its texture, etc[1]. The moisture is lost due to evaporation and heat transfer, as the material cools down. Thus, the material crosses glass transition T_g and becomes solid. No simple deterministic model is available to describe satisfactory dynamic, multiphysic and multiphase phenomena during expansion. Current models[2,3,4] are too complex to be coupled with simple mechanistic model of co-rotating twin-screw extrusion process, in order to predict the cellular structure of starchy foams.

Our objective is to elaborate a phenomenological model of expansion, simple enough to be coupled with Ludovic®[5], a simulation software of twin screw extrusion process. From experimental results that cover a wide range of thermomechanical conditions, a concept map of influence relationships between input and output variables is built. It takes into account the phenomena of bubbles nucleation, growth, coalescence, shrinkage and setting, in a viscoelastic medium. The input variables are the moisture content *MC*, melt temperature T_p, specific mechanical energy *SME*, shear viscosity η at the die exit, computed by Ludovic®, and the melt storage modulus $E'(T_p>T_g)$. The latter represents the elongational viscosity, and takes into account the influence of formulation. The outputs of the model are the macrostructure (expansion indices and anisotropy factor), and cellular structure (fineness) of solid foams, determined by X-ray tomography. Then a general model is established (R^2 = 0.88): $VEI=\alpha(\eta/\eta_0)^n$ in which *VEI* is the volumetric expansion index. The model parameters, α and n depend on T_p, *MC*, *SME* and *E*'. The link between macroscopic anisotropy and fineness is also established, allowing the prediction of cellular structure (R^2 = 0.84). Finally, the model is validated using experimental data of wheat flour extrusion, enriched with fibre, from literature, with R^2 = 0.77 for predicted *VEI*.

The integrative modelling approach of the extrusion process planned in this work will further provide users from academy and industry with the necessary tools to formulate and elaborate extruded starch based composites with potentially improved functional properties. The possibility of optimizing the process will include criteria such as minimizing energy with limited loss of product quality.

References

[1] P. Babin, G. Della Valle, R. Dendievel, D. Lourdin & L. Salvo. *Carbohydrate Polym.*, **68** (2007) 329-340.
[2] M. Amon & C.D. Denson. *Polym. Eng. Sci.*, **24** (1984) 1026-1034.
[3] J. Fan, J.R. Mitchell & J.M.V. Blanshard. *J. Food Eng.*, **23** (1994) 337-356.
[4] S.H. Alavi, S.S.H. Rizvi & P. Harriott. *Food Research Int.*, **36** (2003) 309-319.
[5] B. Vergnes, G. Della Valle & L. Delamare. *Polym. Eng. Sci.*, **38** (1998) 1781-1792.