Effect of water content on viscoelastic properties of amorphous potato starch: DMA measurement

Magdalena Kristiawan, Laurent Chaunier, Sofiane Guessasma, Guy G. Della Valle, Denis Lourdin

Effect of water content on viscoelastic properties of amorphous potato starch: DMA measurement

M. Kristiawan, L. Chaunier, S. Guessasma, G. Della Valle, D. Lourdin

INRA, UR 1268 Biopolymers Interactions and Assemblies (BIA), BP 71627, 44316 Nantes

Introduction

Due to its mechanical properties and the absence of endogenous lipids, amorphous potato starch is offering promising prospects as smart material with shape memory (SMP) (Fig. 1) despite its sensitivity to water[1].

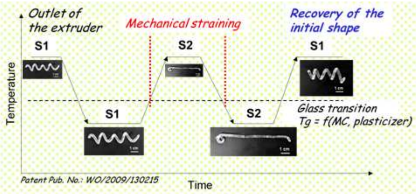


Fig. 1. SMP Programming

Shape recovery (>90%) is triggered by heating above Tg and water uptake.

Commonly used approach for modeling the thermo-mechanical behaviour of SMP is based on the theory of linear viscoelasticity[2,3].

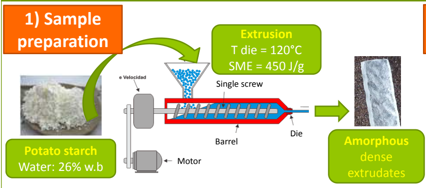
Objectives

The time and temperature dependencies of linear viscoelastic behaviour of amorphous potato starch obtained by extrusion was investigated by dynamic thermomechanical analysis (DMA) in order to build a constitutive model that takes into account the **dehydration effect** occurring during DMA analysis.

A master curve of the relaxation modulus was built to describe the viscoelastic properties on a large time domain.

Material and Method

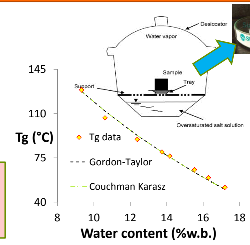
1) Sample preparation



***The DMA** was performed in tensile mode (ε=0.05%) in frequency range (0.1-50 Hz) in function of initial water content (8-17% wet basis) and temperature (25-105°C)*

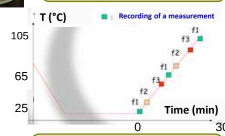
2) Water content adjustment (20°C)

+ Calibration curve: Tg DSC = f(MC)



3) DMA Analysis

a) Simultaneous frequency-temperature sweep



b) Batch sampling during DMA analysis at selected T °C for dehydration study

Results

Figure 1. Temperature - water content dependence revealed by DMA (Water content or MC was obtained by method 3b)

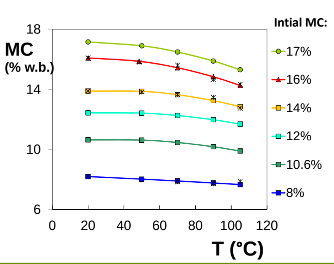


Figure 2. Correction of modulus (E' & E") according to actual water content (Modulus was obtained by method 3a)

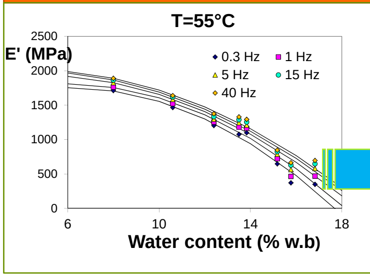
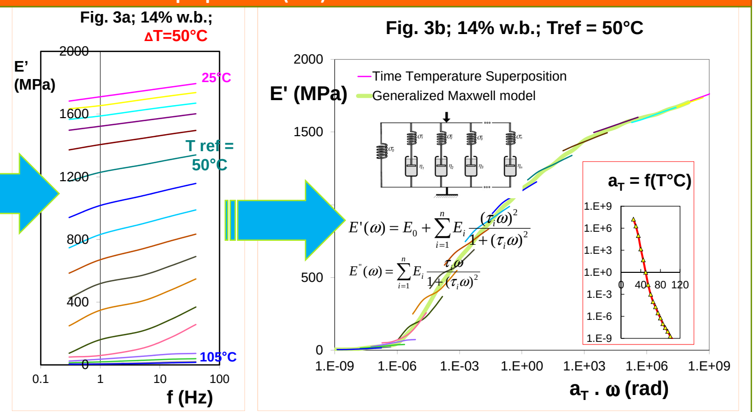
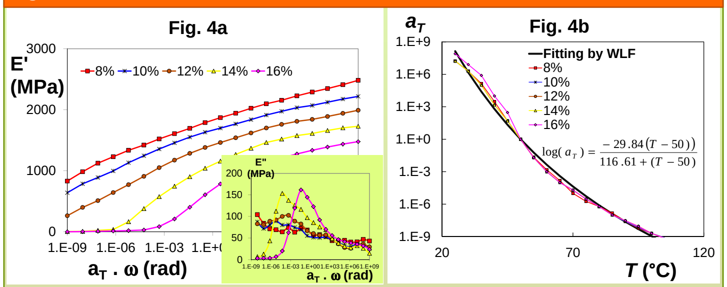


Figure 3. Construction of master curves (E' & E") using Time Temperature Superposition (TTS) for each discret water content



Water loss during DMA experiments was evaluated by thermogravimetric analysis and Tg (by DSC) used as calibration curve (**Fig. 1**). E '(ω) and E" (ω) were obtained as a function of the actual water content in the range of studied temperatures (**Fig. 2**). The principle of TTS, using the translation factor a_T (T) was applied on the isotherms of E' (**Fig. 3a)** to obtain a master curve which then was modelled using generalized Maxwell model (**Fig. 3b**).

Figure 4. Master curves & shift factor of all discret water content at T ref. = 50°C

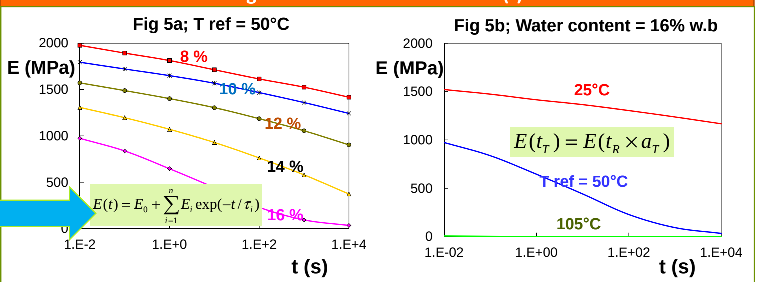


The principle of TTS, using the shift factor a_T (T) allowed us to obtain master curves of storage and loss modulus for all water content. The storage modulus increases with the increasing frequency whereas the loss moduli exhibited a maxima (**Fig. 4a**). The shift factors a_T (T) from all water content can be fitted by a WLF relation (**Fig. 4b**).

Table 1. Coefficients of the generalized Maxwell model, from Fig. 3b

τ_i	MC (%)	8	10	12	14	16
	E_0	1370	1193	836	283	16
0.1	E_1	149	130	147	193	224
1	E_2	21	23	37	68	163
10	E_3	160	122	138	191	231
100	E_4	56	82	101	144	223
1000	E_5	107	123	145	203	92
10000	E_6	128	134	183	245	48

Figure 5. Relaxation modulus E(t)



The modulus E(t) (**Fig. 5a**). was calculated from E'(ω) using the obtained parameters of generalized Maxwell model (**Table 1**). The obtained translation factor a_T (T) allows us to compute E(t) at any temperature and, by interpolation, also its variation as a function of water content (**Fig. 5b**).

Conclusions

1. Linear viscoelasticity behaviour of extruded potato starch was modelled using generalized Maxwell model.
2. Relaxation modulus was determined by tensile stress DMA in a wide range of time in function of temperature for different water content.
3. Relaxation modulus was obtained as continuous function of temperature and water content.
4. The glass transition temperature decreases with increasing water content following models of Gordon-Taylor and Couchman-Karasz.

Perspectives

The results will lead to a dataset of material constitutive laws (relaxation modulus) for modeling and simulation of shape memory effect using FEM.

References

1. Véchambre C., Chaunier C., Lourdin D.; Macromolecular Materials Engineering 295, 115–122 (2010)
2. Diani J., Gilormini P., Frédy C., Rousseau I.; Int. J. Solids Structures 49, 793–799 (2012)
3. Nguyen T.D., Yakacki C.M, Brahmbhatt P.D., Chambers M.L.; Adv. Mater. 22, 3411–3423 (2010)
4. Ferry J.D., Viscoelastic properties of polymers, 3rd edition, John Wiley & Sons (1980)

Contact: magdalena.kristiawan@nantes.inra.fr