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Spatial variability in fundamental material parameters of Gouda cheese

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ABSTRACT

The production process and the ripening of cheese cause chemical and physical variability on a macroscopic level. This spatial variability was examined by measuring fundamental material parameters at different locations in Gouda-type cheese blocks. The verification and quantification of this variability is needed for future research on improving the processing of cheese.

Uniaxial compression tests were used to determine Young's moduli and fracture stresses and strains. Prony series expansions were deduced from stress-relaxation tests. Also the dry matter, protein and fat content and pH of the cheese were determined. Young's modulus and the residual Prony coefficients were significantly higher near the crust compared to the center. The fracture stress and strain were inversely proportional to young's modulus and thus lower near the crust. The spatial variability of the fundamental parameters could mainly be explained by the dry matter variability.

1. Introduction

Cheese is a staple food that is consumed throughout the world. According to statistics from the Food and Agriculture Organization, almost 20 million ton of cheese was produced worldwide in 2010 (FAOstat, 2010). Numerous articles on the chemical, textural and rheological properties of cheese exist (Everett and Auty, 2008; Hort and Le Grys, 2001; Muliawan and Hatzikiriakos, 2007). In recent years, the research on cheese has extended to the domain of numerical simulations. The use of simulations to replace complex and time consuming physical experiments is becoming increasingly popular in the food industry. Finite element modeling (FEM) is a powerful framework to model complex mechanical and rheological behavior of food and other biomaterials like fruit, vegetables, meat, bread, dough and cereals (Celik et al., 2011; Chakrabarti-Bell et al., 2010; Goñi and Salvadori, 2010; Li et al., 2012). More specifically for cheese, finite element models have been used to simulate its cutting process (Goh et al., 2005), to model heat transfer in cheese (Caro-Corrales et al., 2010; Lezzi et al., 2011), to model the salt diffusion in cheese during the brining process (Bona et al., 2007) and to model the rolling process of Mozzarella (Mitsoulis and Hatzikiriakos, 2009).

In the above papers cheese was always considered as a homogeneous material, but during the production process of cheese, especially during the brining, chemical gradients will develop. Due to these gradients structural and textural attributes also differ throughout the cheese. Salt and water mass transfers take place in opposite directions as the brining proceeds (Pajonk et al., 2003). Salt will transfer from the outside to the center of the cheese block, while water will transfer outward from the center. This causes significant gradients in NaCl concentration and dry matter content (Luna and Chavez, 1992; Simal et al., 2001). During the ripening period some of the gradients become more distinct, while other gradients are flattened. The ripening process implies water losses due to the dehydration of the cheese and salt redistribution to obtain a uniform salt distribution, an important factor in cheese ripening (Zorrilla and Rubiolo, 1994). Since molecular transport takes some time, a certain period is required for the achievement of uniform profiles of salt concentration throughout the cheese (Gomes et al., 1998).

The heterogeneity of cheese is not limited to chemical parameters. There are also significant gradients in cheese in regard to textural parameters like elasticity and hardness (Abraham et al., 2007). Although the chemical and textural heterogeneity is studied in literature, untill now there is no extensive description of the variation in fundamental material parameters. This is however required to obtain a realistic and valid FE model that takes this

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spatial heterogeneity into account. The aim of this research is therefore to identify this spatial heterogeneity on a macroscopic level by determining the fundamental material parameters in Gouda-type cheese blocks.

When only small deformations are applied, cheese will behave as a linear viscoelastic material. Linear viscoelasticity is often modeled using the Generalized Maxwell model (Roylance, 2001). This model consists of a series of viscous Maxwell elements connected in parallel with a Hookean spring. The elastic component, represented by the spring, is defined by Hooke's law (Eq. (1)). The stress σ in the material is related to the strain ε with the parameter Young's modulus E, which is constant for small deformations. A higher value of Young's modulus corresponds to a higher material stiffness (Gunasekaran and Ak, 2003).

$$\sigma = E \cdot \varepsilon \tag{1}$$

The Maxwell elements introduce the time-dependent relaxation behavior of the material. This series of elements is often represented by a Prony series expansion (Park, 2001; Van Loocke et al., 2008). The relaxation function $G(t)$ is defined by Eq. (2), where τ_i are time constants for $i = 1 \ldots n_G$ respectively. G_∞ is the residual Prony coefficient, representing the material behavior at an infinite relaxation time. The dimensionless constants G_i and G_∞ are normalized so that they add up to 1 (Eq. (3)).

$$G(t) = G_\infty + \sum_{i=1}^{n_G} G_i e^{(-t/\tau_i)} \tag{2}$$

$$G_\infty + \sum_{i=1}^{n_G} G_i = 1 \tag{3}$$

The material behavior of cheese at fracture is described by the fracture stress and the fracture strain, i.e. the stress and strain at which a cheese sample fractures during compression.

2. Materials and methods

2.1. Cheese preparation

This research was performed on 8 weeks old Gouda type cheeses, produced in a small cheese company situated in Mol (Belgium). The cheese blocks were rectangular and had standard dimensions of 47 × 30 × 10 cm (Fig. 1). They were stored under ideal ripening conditions at a temperature of 13 °C and a humidity of 85%.

One block of cheese was used for chemical measurements, i.e. the determination of dry matter content, fat content, protein content and pH. Three cheese blocks from the same batch were used to examine the fundamental parameters and the corresponding dry matter content.

Preliminary measurements of chemical and textural parameters showed that the blocks of cheese can be considered to be symmetric in the length and width of a block (results not shown). This symmetry does not exist in the height, probably due to the pressing of the cheese and gravitational forces during ripening. The upper side of the cheese is the side that was on top while the cheese was pressed during production.

Every block of Gouda cheese was prepared for measurements following the same procedure. Three slices of cheese with a thickness of 3 cm were taken out of the middle section of the block and 3 slices were taken at one side section of the block (Fig. 1). To obtain every measurement in 3-fold, the three slices from the middle section (M) were considered to be the same, as well as the three slices from the side section (S). The assumption of equality of the slices was made based on preliminary research (results not shown).

To investigate the heterogeneity in the x-direction slices from the middle section were compared with slices from the side section. Heterogeneity in the y- and z-direction was analysed by taking samples at different places in one slice (Fig. 2). Every slice was considered to be symmetric around the middle line. Six samples were taken from every side of a slice. Both left and right sides were used to determine dry matter content, fat content, protein content and pH. The samples at the left side were used for compression tests to determine Young's modulus E and the fracture stress and strain. The samples at the right side were used for stress relaxation tests, from which Prony series were deduced.

2.2. Sample collection

When determining the chemical parameters in one cheese block, pH was determined directly in each location. Afterwards, the cheese samples were grated and for each location a homogeneous mixture of 3 similar slices was made. Samples for chemical measurements were taken out of this mixture.

The samples used for the compression and stress relaxation tests were cylindrical in shape with a diameter of 18 mm and a height of 27 mm (± 0.5 mm), based on the norm ISO 17996 (2006). The samples were taken from the blocks of cheese using a cylindrical corer. They were cut at the desired height of 27 mm using a wire cutting device. Every sample was stored at room temperature for 60 min. During this hour the samples were properly protected from the air to prevent drying at the surface.

After the fundamental measurements were performed, the cylindrical cheese samples were grated and mixed by location to determine the dry matter content.

2.3. Chemical analysis

The dry matter content was measured by putting three samples of grated cheese (3 g) on pre-dried and weighed glasses with sand and spatulas and mixing the cheese with the sand. The samples were dried in an oven (Jouan, St-Herblain, France) at 105 °C for

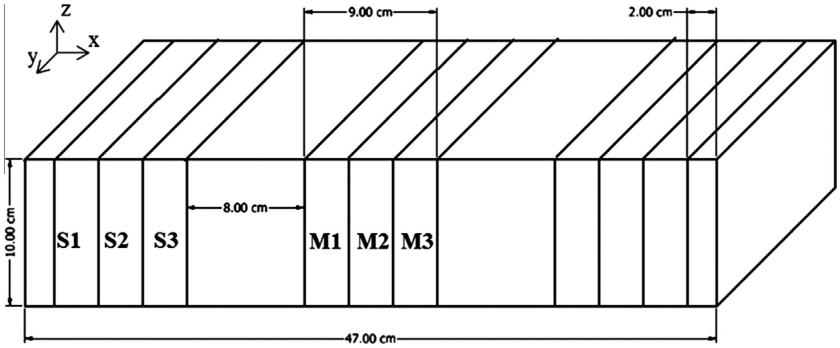

Fig. 1. Geometry of a cheese block and the division of slices in groups.