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A composite model for wheat flour dough under large deformation

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Abstract

The mechanical behaviour of dough, gluten and starch were studied in an effort to investigate whether bread dough can be treated as a two phase (starch and gluten) composite material. Mechanical loading tests revealed rate dependent behaviour for both the starch and gluten constituents of dough. There is evidence from cryo-Scanning Electron Microscopy (SEM) that damage in the form of debonding between starch and gluten occurs when the sample is stretched. In addition, a reasonable agreement is seen between the Lodge material model and the compression test data only, indicating again that possibly 'damage' is essentially debonding which does not occur under compression, unlike tension and shear loading. A composite finite element model was developed using starch as filler and gluten as matrix. The interface between the starch and gluten was modelled as a cohesive contact interaction. When the interaction of starch and gluten is strong, as indicated for the dough with no damage, the stress-strain curve is always higher than the gluten stress-strain curve under both tension and shear loading. In contrast, when damage is activated in the form of debonding, the dough stress-strain curves under tension are seen to cross over the curves for gluten and therefore leading to lower stress values than in gluten. No damage/debonding occurs under compression when a damage function is used which is in good agreement with the experimental data.

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Keywords: Dough, Gluten, Starch, Visco-hyperelastic, Cohesive contact

1. Introduction

Baking performance and quality of bread produced are strongly dependent on the mechanical behaviour of dough used. Even though bread dough is a simple mixture of wheat flour, salt and water, its

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mechanical behaviour is surprisingly complex. Two major components of dough which are believed to influence the mechanical properties of dough are starch and gluten. These two phases interact by forming starch-starch, starch-gluten or gluten-gluten interactions [1]. This work investigates the mechanical behaviour of dough, gluten and starch. The possibility of damage at the interface between the starch and gluten is investigated. This is performed by using a two phase (starch and gluten) composite material model and comparing the model predictions to experimental stress-strain data for dough tested under various loading conditions.

2. Materials and Methods

Wheat flour dough was prepared using the procedures by [2]. The flour used is strong white bread flour purchased from Wessex Mill in Oxford, United Kingdom. A mixture of 198.5 g of wheat flour, 120 g of distilled water and 1.5 g of sodium chloride is used to make the dough (62%, 37.5% and 0.5% of wheat flour, water and salt respectively). Starch and gluten were separated from the dough by washing the dough under running tap water to remove the starch granules. The sample was gently rubbed using fingers to ensure that the starch was removed from the gluten matrix. The remaining water in the gluten was allowed to drip out of the sample by allowing the sample to rest for approximately 60 minutes on water absorbent paper. A similar procedure was performed to collect the starch granules. Rather than draining the water containing starch during the washing of dough, it was collected in a steel pan. The starch/water solution was allowed to dry for ~24 hours at a temperature of 22 ^0C and 50% relative humidity. The drying process was assisted by a fan. It was found that leaving the samples to dry for longer than 24 hours did not lead to significant further weight loss. The dough, wet gluten and reconstituted wet starch were formed into cylindrical samples of 40 mm diameter and 3 mm height for compression testing, and 6.8 mm diameter and 27 mm height for tensile testing [2]. A 40 mm diameter parallel plate geometry with a 3 mm gap was used for the rheometer tests. Wet/native gluten as opposed to vital gluten was used because the gluten network formed during mixing of dough is still retained, which makes it possible to determine the properties of the gluten as it appears in the actual dough samples [3]. The reconstituted wet starch was obtained by adding dry starch with a prescribed amount of water (i.e. 30%, 50% and 70% w/w). It was found that at 30% and 50% w/w, the starch appeared to be very dry, still in powder form, whereas at 70% w/w the starch formed a paste-like substance which could easily be formed into samples. Therefore starch with 70% w/w was used for the tests. Further investigations for estimating the 'correct' amount of water in starch are currently underway.

Mechanical tests under tension and compression modes were performed using the Instron 5543 with 100N and 1kN load cells respectively. The tests were performed at constant true strain rates as opposed to constant crosshead speeds. Shear tests were performed using the rheometer model TA2000ex. Cryo-SEM tests were performed on dough and gluten samples mixed from the same batch. The dough samples were stretched and compressed manually just before exposure to liquid nitrogen, such that comparison could be made with images of unstretched samples. All specimens were slushed in liquid nitrogen under vacuum conditions before being transferred to the cryo chamber; they were freeze-fractured, sublimated at -90 ^0C for 2 minutes and gold-sputtered before being imaged in the SEM chamber.

3. Results and Discussion

The results from the mechanical tests on gluten are shown in Fig. 1. Gluten shows rate dependent behaviour under compression, tension and shear modes, and energy dissipation under a cyclic-compression mode.