

Microstructure Informed Modelling of Adulteration Evaluation in Food New Approaches in Modelling to Characterize food Microstructures

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Abstract

Objectives: To analyze the characteristic properties of certain food products, their microstructure is designed through many food-processing operations. Generally the properties of milk products such as cheeses, yoghurt, spreads and whipped products are analyzed using their structures. Pasta, meat products like sausages are fabricated cereal products. Their microstructure is a colloidal structure such as gels, emulsions, foams or any of these combinations. **Methods/Analysis:** To analyze how the structure is designed and the way it is related to a property many tools of microscopy are currently in use. **Findings:** A new technique in three dimensional modelling known as function-based procedural representation is fine tuned to model the internal microstructures and the characteristics properties of certain food products. **Novelty/Improvement:** This microstructure model is compact, precise and parameterized. There is no need for generating secondary structures and they can be rendered and fabricated directly. It is also easy to apply geometric transformations on these microstructures.

Keywords: Function Representation, Microstructure

1. Introduction

Some of the texture properties like firmness, softness, cohesiveness, rubbery, elasticity, pastiness, crumbliness and functional properties of the food products are controlled by the microstructure. Microscopy is used to analyze the affected physiochemical, transport and nutritional properties of the food products. Since the consumers expect good quality of dairy products their texture and functional properties are important in quality evaluation. Better quality yields higher revenues and consumer satisfaction¹. For a good micrograph analysis microscopists experience and accuracy are important. Sometimes the technicians confirm their own hypothesis in their observation. This was one of the most common pitfalls observed. Only by the subjective evaluation of image content

visual observation is done². For quantitative estimations human natural imaging system is not completely trusted as human judgment lacks objectivity. The measurements taken automatically by image analysis methods are quantitative, objective and repeatable. The digital micrograph provides quantitative information in the form of numerical data. Therefore, the quality of digital images cannot be compared with human visual capabilities. Human visual system can recognize and isolate object features of their interest from a scene. Although humans can discriminate image features, computer measurements are objective and deterministic. Recently digital images are analyzed automatically. Automatic analysis of digital images of food microstructure can be paired up with many different imaging technologies, such as electron, confocal and light microscopy³. The site-bond model uses a lattice that is

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halved and truncated with cellular model of octahedron⁴. This simulates the elastic properties to evaluate the pore size⁵. For regular representation of solid this truncated octahedral cellular microstructure of food particle can be used. The blending of unit cells is done by structural beam elements⁶. The mathematical analysis cannot be used to find out the relationship between the global elasticity and local element properties. To derive the relationship, the site-bond model for elasticity was repeatedly worked out. The structural beam elements are replaced by springs with elastic property. Now mathematical analysis can be used to find the relationship between spring constants and the parameters of elasticity. The aim of this work is modelling of the food particles and analyzes their macroscopic behavior and adulteration evaluation using site-bond technology. Attributes such as number of pores, size of the pore, volume and scattered area size of food particles are considered for modelling⁷. The food microstructure is clearly visible when site-bond assembly is employed between the bonds and the cells in the center. For powdery food particles the particle size varies. Those difference in size are assigned to bonds. Different loading conditions are applied to the food microstructure obtained. The bonds that fail to the loading conditions are removed. This automatically simulates the evaluation of damage. We vary the attributes of food microstructure and the above analysis is performed repeatedly for a quantitative study. The simulation results are compared with the experimental data of food particles to find the damage level.

2. Prior Work

2.1 Image processing and Image Representations by Segmentation

Image segmentation is partitioning of the image domain into no overlapping regions. The purpose of segmentation is to mark the area of interest accurately in the micrograph. Segmentation should be in such a way that the area of interest and the corresponding feature in the image area is close⁸. Thresholding is done for food microstructure. The region is partitioned into lighter and darker colors by using a scalar value⁹. A Scanning Electron Microscope (SEM) image in two-level labeling of Ragusano cheese is obtained, partitioning the input image into background and foreground (Figure 1). Although there are so many sophisticated methods this native method is fast and intuitive for the operator and it often gives acceptable

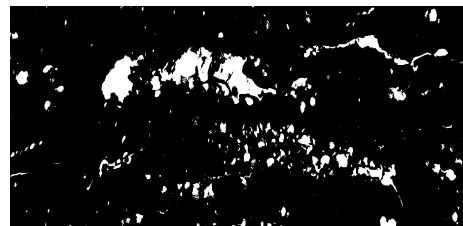


Figure 1. A scanning electron microscope (SEM) image of Ragusano cheese. The binarised image is obtained by manual thresholding.

results. The crack in the protein matrix of the Ragusano cheese is accurately detected and marked (Figure 2(a)). The respective binary image is obtained (Figure 2(b)). On zooming the image we can see many pores missing (Figure 3(a)). The respective binary detail of the micrograph with missing pores is obtained (Figure 3(b)). The micrograph is again zoomed out to get more details (Figure 4(a)). The corresponding binary image is observed noisy (Figure 4(b)). Median filter is applied to reduce the noise. Before thresholding the resulting image is observed to contain less spurious spots (Figure 4(c)).

3. Modelling and Simulation of Food Microstructure

A material structure of size 10L_10L_10L is considered and so the cellular structure contains 8630 cells. The generated model using site-bond technology has 8630 sites and 56630 interconnections. The food microstructure is a three-phase composite structure composed of anhydrous food grain, hydration products and pores. At the center of the cell are the anhydrous food grains, the pores according to their sizes occupying the interfaces and the other places in the cell are occupied by hydration products. The anhydrous food grains and the hydration products on their combination exhibit elastic property. The mass densities of different types of hydrates are obtained and the properties of hydration product are averaged. The attributes having elastic properties and that are macroscopic in nature are obtained using tests of nano-indentation and X-ray photoelectron spectroscopy¹⁰.

3.1 Algorithm for Incorporating Microstructure into the Site-Bond Model

Step 1: To calculate the model length scale, ML the volume and area of scattered food particles are used. As

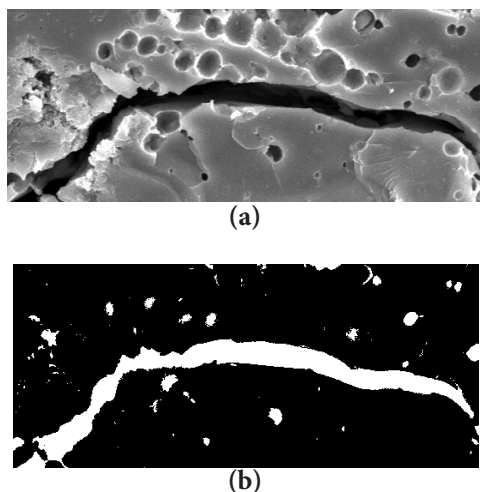


Figure 2. A detail of the micrograph in Figure 1. The crack in the protein matrix is accurately detected and marked.

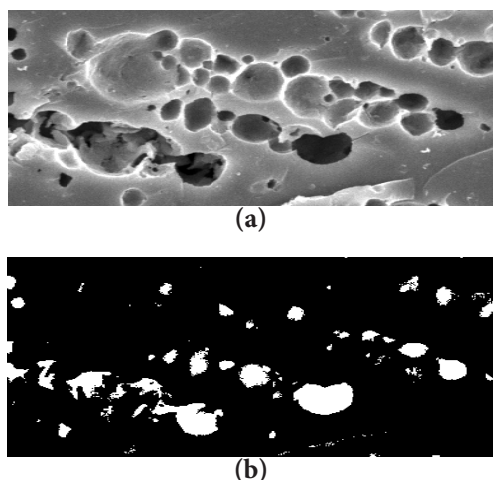


Figure 3. A detail of the micrograph in Figure 1. Most pores are missed.

per the experimental results of area of scattered food particles of different measurements, they are assigned randomly to all sites of the food cells. Random numbers $0 \leq \text{ran} < 1$ are generated uniformly by a generator so that they are applied to individual sites of the food particles¹¹.

Step 2: A random number ran is generated for each site and the assigned grain size is derived as $\text{GR}_i = F^{-1}(\text{ran})$, where $F(\text{GR}_i)$ is the cumulative probability of grain sizes presented in Figure 5. Then comparative study is done with the simulated and experimental measurement of the area of scattered food particles as shown in Figure 6. It confirms that

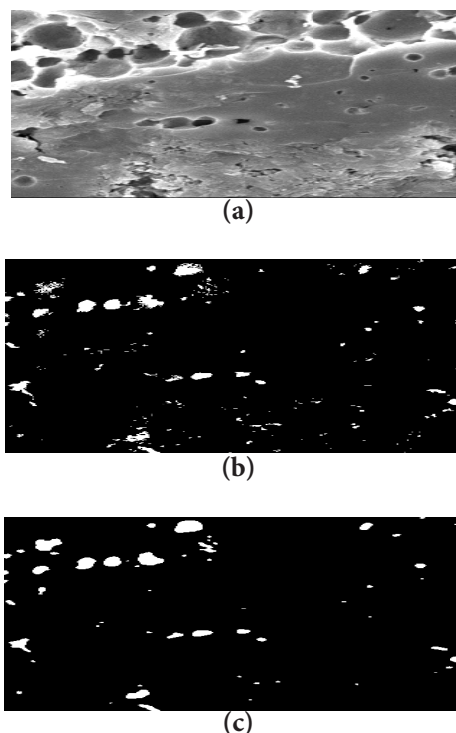


Figure 4. A detail of the micrograph in Figure 1. The binary image is very noisy, whereas if noise removal (median filter) is applied before thresholding the resulting image shows less spurious spots.

the simulated area of scattered food particles of powdered food particles fits the measured area. Powdered food particles are considered to be spherical in shape. Each food cell has one spherical powdered food particle GR_i .

The volume of powdered food particle, $V_{\square_a}$, and the volume of the food cell structure with X cells are used to calculate the cell size via $V_{\square_a} X \text{ML}^3 / 2 = \sum_i 4\pi \text{GR}_i^3 / 3$. Using macroscopic elastic attributes with determined food cell size, the properties of normal and transformed springs in each bond are calculated.

Step 3: The energy value of failed bonds is calculated by measuring the pore size and the area of scattered food particles. As in Step I, pores are assigned randomly to the bonds by generating a random number ran using a generator. This random number is just a face number of the food cell. This generation does not constrain the position of the pore in the food microstructure. This generation and assignment is repeated until the expected porosity in the modelled food microstructure is reached¹². The energy level of failed bonds is

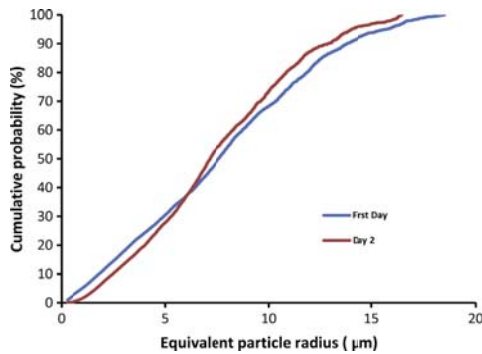


Figure 5. Particle size distribution of powdered food particles.

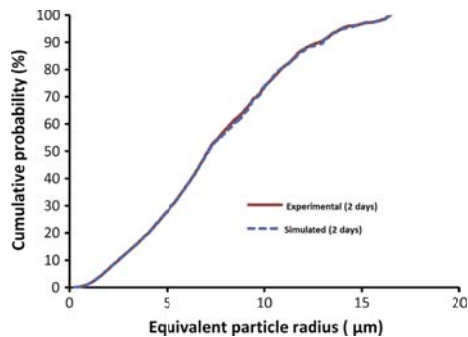


Figure 6. Comparison between the simulated and experimental particle size distributions of 2 days old food particles.

estimated from the expected surface energy and the blended area associated with the bond via $FG_f = 2\sigma A_c$. Since the size of the pore varies the spring constants exhibiting elasticity are same but energy value of failed bonds are different. This is due to the presence of pores with different sizes in bonds. They vary from $2\sigma A_0$ to the maximum and zero to the minimum. Zero size is for the pore area close to the blended area of the square face or hexagonal face. Before the next loading condition is applied the bond is removed if the pore area in a bond is equal to or larger than the corresponding face area.

3.2 Experimental Results

Figure 7 shows the predicted damage evaluation food particles at two days of manufacture under plane strain. In the initial stages we observe that the graph is non-linear.

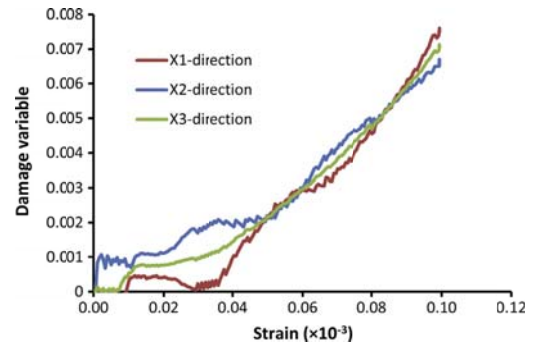


Figure 7. Damage evolution in food paste under plane strain.

Each bond in the food cell is subjected to severe transformations at the same step of applying loading condition and compared with the transformation applied on a single axis. As a result the bonds are broken immediately and fastly. So at the peak point the tensile strength and strain are lower. The corresponding evolution of damage parameters is illustrated in Figure 7. At the failure level of bonds it is seen that the values of damage parameters are less. Under plain strain since there was a fast breakage of bonds it shows that even though the blending is hard due to damage it is liable for easy breakage. Also the damage development is different in different direction. Under plane strain the generated micro food particles exhibits different levels of damages in different directions in the food paste specimen. The microstructure of food particle worked out is heterogeneous since the size of the pores are different at each bonds. Figure 7 shows the damage evolution of food paste under plain strain. The damage parameters and the strain are used for damage evolution.

4. Conclusion

As a next phase of site-bond model a concept for relating key microstructure characteristics of food particles to its macroscopic behavior is proposed. Because of this strategy the food particle is considered as a volumetric microstructure with three dimensions: (1) the length determining features are the volume and area of scattered food particles of powdered food particles (2) the size of the pore and area where the pores are distributed are used to calculate the failure of bonds. For modelling the food microstructure attributes of elasticity and surface energy are acquired. Thus macroscopic properties from their intermediate principles can be predicted by this

technology. From the above findings the following conclusions can be drawn.

- Food adulteration, stress-strain response and fracture energy depends on the loading condition applied.
- With the available macroscopic effects the constitutive behaviors of structures can be analyzed by implementing the above fact.
- As the loading conditions become complex the damage evolution is not uniform but exhibits different failures at different directions.
- The mechanical properties and adulteration evaluation are heavily affected by the size of the pore. As the size of the pore increases although the bond appears to be hard it is liable to break immediately. The linear Hasselmann's equation is applied to express the Tensile strength-porosity relation of food grain and it is flawless in matching the experimental results.
- The area of scattered food particles forms an important attribute in damage evolution. Larger fractions of large pores produce more brittle response. This result is good with basic fracture theory.

The work provides new internal views of the failure behavior of powdered food particles. The above proposed site-bond technology can be used for the prediction of transformations in mechanical properties and firmness. Also this strategy allows for the fitting of time-dependent effects in food-based products. These opportunities are subject of ongoing works.

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6. References

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