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STRUCTURAL AND MECHANICAL PROPERTIES OF THE CUTTING OBJECT

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Abstract
The article covers the properties of capillary-porous multiphase food half-finished products processed by the method of sliding cutting, as well as research of cutting objects using various rheological models.

Keywords: rheological model, blade, quasi-static mode, plastic deformation, macromolecule, micro-teeth, spongy protein framework, food polymer, sliding cutting, food mass, negoscalpic properties.

Introduction

N.E. Reznik [1] introduced negoscalpic properties into consideration, they denote a complex of material characteristics, food characteristics for its cutting performance, and are mainly determined by the structural-mechanical and frictional properties of the cutting object.
At present, it is generally accepted that without describing the structural-mechanical properties of food masses, it is impossible not only to study the patterns of their formation, but also to substantiate the optimal parameters of their processing at the modern level [2, 3, 4, 5]. Friction indicators are the most important in the complex of negoscalpic properties of the cutting object. Friction by its nature is a complex thermodynamic process associated with heat and mass transfer and other flows, the mutual influence of which determines the level of resistance to the movement of bodies. Most researchers believe that the general mechanism of sliding friction is due to the action of two main factors: adhesive and deformation.

Main part

Despite the specificity of the deformation behavior of various materials in the sliding cutting process and the resulting different requirements for the cutting tool and cutting conditions, it can nevertheless be argued that the overwhelming majority of food materials, as a rule, also have common properties in the form of a complex multiphase structure, relatively low strength characteristics, pronounced highly elastic, frictional and adhesive properties.
Taking into consideration a wide range of physical-mechanical properties of food materials [3, 4, 5], in our work, cutting objects were limited to products and half-finished products related to capillary-porous bodies and characterized by the above-mentioned properties. The experiments were carried out

with products and half-finished products of bakery, macaroni and flour confectionery production, for which, as experience shows [6, 7], the use of sliding cutting is most effective.

Food polymers are structures, as a rule, formed by a spatial spongy protein framework, the cavities of which contain amorphous inclusions, liquids, vapors and gases. The protein framework is the strongest structural part of the food materials under consideration. It consists of oriented conglomerates interconnected by various kinds of cross-links, the strength of which may differ by several orders of magnitude. Starch is the main filler of the structure, the surface of the grains of which is connected with the spatial network of molecules of swelling proteins by means of grain phosphatides and lipoprotein membranes. The nature, shape, size and structure of starch grains affect its hydration in the structure of half-finished products.

Cellulose also plays a certain role as a filler in the structure: having a high porosity, it swells in water due to capillary wetting. Cellulose can significantly reduce the high elasticity properties of proteins. According to the recipe of a half-finished product, natural and introductory fats are plasticizers of its structure.

Due to heat treatment during baking, the confirmation of the molecules of the main polymers of the grain changes, the content of free water in the structure decreases, the dough loses its ability to flow under the influence of gravitational forces. The plastic-elastic structure of the dough turns into an elastic-brittle plastic foamy crumb structure.

The objects of research were rye and wheat bread, rusk plates, biscuit half-finished product, molded long-tube macaroni. The main technological indicators of half-finished products were in accordance with the standards and technical conditions.

These food materials are, by nature and phase state, a highly concentrated starch-protein xerogel. The presence of open air-pores of various sizes in it, the inhomogeneous thickness and structure of their walls complicate the conditions for measuring mechanical characteristics. These intervals have not only flexible and elastic properties, but also significant plasticity. The elastic properties due to the content of the gas phase, as well as plasticity, make their elastic moduli depend on the magnitude of the stress value and strain speed. With an increase in the proportion of gases, elastic deformation lags behind the stresses, which leads to an increase in the magnitude of the moduli. For structured dispersed systems, which include the materials under consideration, high structural viscosity and elasticity of shape are characteristic [3].

Most food products and half-finished products are not phenomenologically homogeneous, but are dispersed systems consisting of two, three or more phases [3, 5]. In this regard, the apparatus of rheology and mechanics of a continuous medium, which study homogeneous and quasi-homogeneous materials on the assumption that they are continuous media, can be applied to food materials only if the dimensions of the smallest elements of dispersed phases are much smaller than the dimensions of the elements themselves, the total deformation which need to be studied. Hence, it can be seen that in order to describe the destruction of food material by blade micro-teeth, it is necessary to consider the physical-chemical mechanisms of deformation and changes in the properties of elementary particles of the frame and fillers during the cutting process.

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It is known [4] that the structural elements of the molecular chains of food polymers proteins are amino acids, the atoms of which are firmly connected to each other. Breaks of protein molecules are possible only at peptide bonds, because their strength is low. Due to fluctuations and uneven strength of chemical peptide bonds, protein molecules and their supramolecular formations have significant flexibility. In this case, individual links of the protein chain can shift relative to each other around the "hinge areas", i.e. peptide bonds with a comparative "immobility" of the remaining elements of the molecules.

Since the molecules and macromolecules of proteins are bound to the next macromolecules of various kinds by chemical and physical bonds, a change in the position of one link or the entire molecule entails a change in the position in the environment of the molecules. In this connection, changing the position of the macromolecule is always difficult. The nature and strength of bonds even along one protein molecule are very different from each other. These factors largely determine the conditions for the deformation of the studied objects and the destruction of the sludge framework.

Under the action of the blade of the cutting tool on the half-space of homogeneous deformable bodies at the points of contact, an increase in stresses is observed and the area of the body adjacent to the contact zone passes into a plastic state. A further increase in the external stress does not contribute to an increase in stresses in this zone, but causes an increase in the rate of plastic deformation. Destruction at the point of contact is carried out due to the plastic pushing back of the material under the influence of external forces. Obviously, the destruction of homogeneous media occurs under the condition of exceeding the stresses caused in the contact zone by external forces, the yield stress of the destroyed material. This fracture model is applicable to rigid-plastic isotropic bodies that have a relatively homogeneous structure.

In the case of cutting food materials with an inhomogeneous structure, their plastic deformation is limited by the protein framework. In this case, the stress is initially localized in the areas adjacent to the blade. Due to the high deformation properties of porous food materials in the cutting wedge zone, the contact surface increases, which prevents the rapid growth of contact stresses and contributes to the deformation of a significant volume of the material.

The mechanisms of destruction and deformation differ significantly from each other:

1. Process of destruction is determined by the breaking of chemical bonds, and the process of deformation is determined by overcoming the forces of intermolecular interaction;
2. Fracture and deformation are associated with various components of the stress tensor (fracture with normal tensile stresses, and deformation with shear stresses).

Therefore, in the loaded material, two different processes take place simultaneously. Deformation is a change in chain conformations, which is impeded by intermolecular and intramolecular bonds. Destruction is the breaking of polymer chains. Thus, destruction is a local process, and deformation is a volumetric process.

The difference in deformation and destruction processes is especially noticeable when the load application rate changes. Under static loading, stresses and strains are distributed throughout the sample, each part of which participates in the deformation process and can initiate destruction. Under

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dynamic (impulse) loading, local stresses and deformations arise, which contribute to the destruction of one part of the sample, regardless of what happens in the other part of it. In this case, the stress state of the body can change so quickly that the arising deformations and destructions do not yet have time to propagate, and the stress distribution is already changing, because their speed of propagation can be several times higher than the speed of crack propagation.

It can be seen that the currently accepted methods for studying structural and mechanical properties do not all correspond to the phenomena occurring in the process of cutting with a blade. The discrepancy between the conditions for determining the properties of materials and cutting conditions significantly complicates the use of the information obtained.

Research of the structural-mechanical properties of the cutting object was carried out taking into account the scientific concept of work and the physical model of the process, in accordance with which two main modes were identified. The first mode corresponds to the deformation behavior of the material under conditions of its loading by a wedge moving, as a rule, at a low speed in the direction of feed, and can be called quasi-static. The second mode corresponds to the impact interaction of the blade elements with the cut material during sliding cutting or grinding with a blade and is dynamic.

From the literature [2, 4, 5], it is known that the three-parameter model (Maxwell-Thomson), consisting of the elements of instantaneous E_1 and retarded E_2 elasticity and a viscosity element, is most suitable for describing deformation phenomena corresponding to a quasi-static regime. Taking into account the possibility of destruction of the structure by a cutting wedge with significant deformations (chopping cutting), the Maxwell-Thomson model must be supplemented with a limiting element that is included in the work only at $\varepsilon \geq \varepsilon_{кр}$ (Fig. 1 a).

The impact of micro-teeth on the material during the tangential motion of the blade is characterized by a sufficiently fast application of a load, at which, due to viscous resistance to flow, highly elastic deformations do not have time to appear, and the subsequent formation of an initial micro-notch in the material. Therefore, under the dynamic action of the blade, the properties of the material, as shown by M.N. Klimenko [8] must be modeled with the limiting element σ_s (Fig. 1 b). Such a model can be used in the analysis of the micromechanism of sliding cutting and the study of grinding with a blade, when the movement of the knife is characterized by high speeds.

The batch of half-finished products selected from the production lines for experiments was stored on racks in the rooms of a food enterprise and laboratories at a temperature of 18-20 °C. With varying the exposure duration, the amount of shrinkage was controlled.

The dough was kneaded from macaroni (grit) and bakery flour. Molded macaroni tubes 5.0 mm in diameter and 110 mm in length were placed in a rectangular cassette with dimensions 110x60x40 mm. Cylindrical specimens were used to deform the rest of the half-finished products. To obtain samples of exact height, first, slices of a certain thickness were cut from the material with a special double-edged knife, and then cylindrical samples with diameters of 20 and 30 mm were cut from them. The height of the samples in different series of experiments was 15, 30, and 80 mm. The duration of the action of stresses varied in individual experiments from 5 to 30 s.

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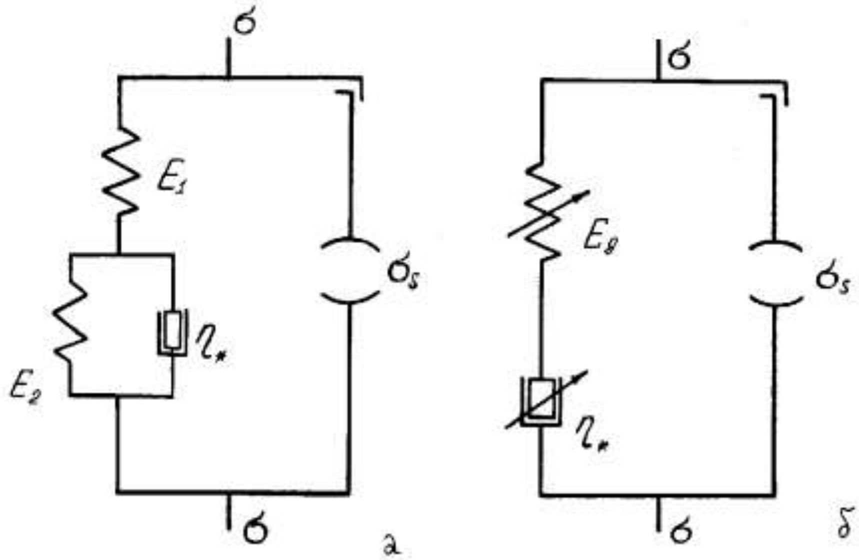

Fig. 1. Rheological models of cutting objects:
a – model of the material under conditions of loading with a cutting wedge; b – model of the material under the conditions of the formation of a new surface.

The specific properties of elastic porous materials necessitate a more accurate account of various factors, in particular, the features of the macrostructure, which have a noticeable effect on their mechanical properties. Variance analysis of the mean and standard distributions of the compressibility values of the object of study, carried out in a preliminary series of experiments according to known methods [9], shows that at the usual level of significance, the difference in deformation of the object of study cut from different zones (rusk plates, bricks of different breads, biscuit half-finished products), should be considered insignificant. Consequently, the discrepancies in the deformation values for different shear zones are accidental and due to errors in intent. The maximum relative value in these tests averaged 5-10%.

When preparing specimens, the inevitable destruction of the cellular porous structure on the cut surfaces should be noted, which can lead to certain changes in the physical-mechanical characteristics of the structure. Decrease in the size of the cut surface with a damaged structure was achieved by using a cylindrical (tubular) knife for cutting out specimens. Research in the field of studying the mechanical properties of elastic porous polymers [28] have shown that the minimum dimensions of samples of porous materials should exceed the linear dimensions of individual cell by 8-10 times.

Conclusions

Capillary-porous multiphase food half-finished products processed by sliding cutting have general properties in the form of relatively low strength characteristics, pronounced highly elastic, frictional and adhesive properties.

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Significant difference in the mechanisms of destruction and deformation makes it necessary to use various rheological models and modes of mechanical action in the study of cutting objects. The first mode corresponds to the deformation behavior of the material under conditions of quasi-static loading with a cutting wedge. In this case, it is possible to use a three-parameter model (Maxwell-Thomson), connected with the limiting element; the second mode is characteristic for the formation of a new surface in the material, the properties of which can be described by the Maxwell model with the limiting element σ_s. Under the high-speed action of the cutting edge, this model is transformed into a Hooke body with the limiting element σ_s.

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