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Development of an automatic device for measuring the coefficients of the Bingham's rheologic equation describing structural and mechanical properties of macaroni products

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Development of an automatic device for measuring the coefficients of the Bingham's rheologic equation describing structural and mechanical properties of macaroni products

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Abstract. The most energy consuming stage in production of macaroni products is drying. Moreover, at this stage, the final quality of macaroni products is achieved. The main element deteriorating the macaroni products is cracking. This paper is devoted to the development of an automatic device significantly accelerating the study of cracking.

1. Introduction

Drying of macaroni products is the most energy consuming and important process affecting their quality.

The main controlled technological parameters of drying are temperature and humidity of the air in the dryer zone, as well as the temperature and humidity of the product itself [1]. However, currently, continuous measurement of the temperature and humidity of processed product is impossible [2].

One of the most important flaws in the quality of macaroni products occurring during drying is cracking.

The origination of cracking during drying of macaroni products was studied by a range of researchers [3–9]. They have discovered that first, the cracks form due to the stresses in the product caused by the contraction of the layers of macaroni semi-products during drying; second, the value of the stresses that the semi-product can sustain without cracking at different drying speed can be evaluated by relative elongation under load.

Current work is aimed at the development of a device for automatic determination of the structural and mechanical indicators of macaroni semi-products during the study of their cracking during drying.

2. Materials and methods

The research studied macaroni semi-products from groups A, B and C made from different mixtures of floor: from durum wheat, soft highly vitreous wheat and wheat baker's flour. The macaroni were made on macaroni extrusion press PESh-30/40 at the extruded mixture humidity of 28-34%.

The macaroni products were dried in a special laboratory setup.

The dependencies of the stress in the dried semi-products were plotted using the setup described below.

3. Development of the device for automatic plotting of the dependencies of stress on relative elongation

The semi-products of dried macaroni products from the perspective of the changes to structural and mechanical properties are usually described by the Bingham's model [10]. This model at constant elongation and narrowing rate is described by eq. (1):

$$\sigma = \left(\dot{\varepsilon}\eta_T + \sigma_T\right) \cdot \left(1 - e^{-\frac{E\cdot\varepsilon}{\eta_T \dot{\varepsilon}}}\right) \quad (1)$$

where $\dot{\varepsilon} = const$ is the rate of axial flow, s^{-1}; σ is normal stress, Pa; σ_T is tensile yield stress, Pa; E is elasticity modulus at linear strain, Pa; η_T is axial flow viscosity, s^{-1}.

Thus, as per eq. (1), there is a clear connection between relative tensile elongation and normal stress.

In the expression, $\varepsilon = const$, while η_T, σ_T, E are determined by the dependencies of the normal stress on elongation.

The authors have elaborated an automatic device to plot these dependencies (Fig. 1).

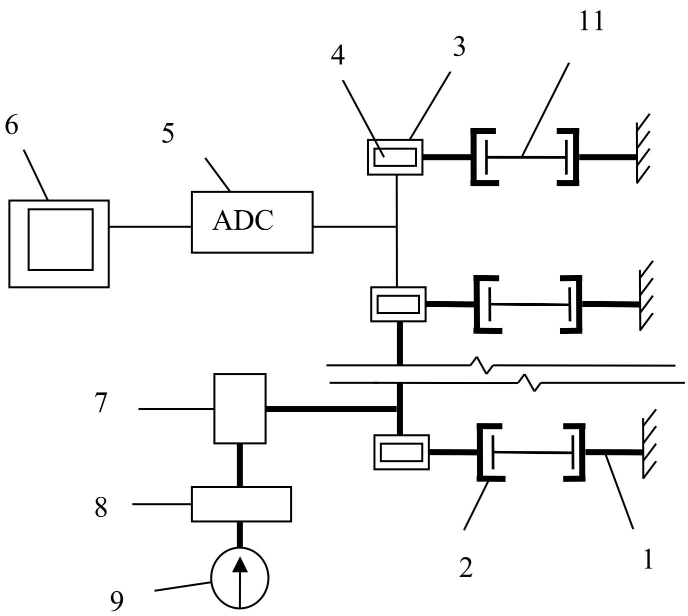

Figure 1. Device for testing tension of food materials: 1) passive grip, 2) active grip, 3) loader, 4) tension sensors, 5) analog-to-digital converter, 6) computer, 7) gear, 8) speed variator, 9) electric motor, 10) metal plate, 11) test specimen.

The device works as follows. The test specimen is a long macaroni product.

One end of the specimen is fastened in the passive grip, the other one in the active grip. The approach of the active grip into initial position is done by moving the loader in reverse direction.

As a result of the system operation (electric motor, speed variator and gear), the loader is put in motion and communicates a uniform tension load to the active grip. The signal received from the tension sensors is registered by the analog-to-digital converter and transmitted to the computer, where it is converted into measured values that are recorded as a data array and time dependence plot into a file.

The implementation of the loader comprising the electric motor, speed variator and gear enables uniform tension of the specimen simultaneously identifying the dependencies both between elongation and rheological properties and between the latter and the loading time. Thus, one can assess the product quality by the time needed for a certain change in the specimen.

The usage of computer processing of the signal in the suggested tensimeter design along with the dependence of the product quality on the specimen loading time allows using it for automatic control and regulation of the technological process.

For instance, Fig. 2 presents the dependence of normal stress on elongation for the moisture of the macaroni products of 22% and their temperature of 75 °C plotted at constant specimen tension rate $\dot{\varepsilon} = 0.167 s^{-1}$.

Evidently, the experimental curve intersects the ordinate axis at 30 kPa, which corresponds to the yield stress of the material and is determined by the Bingham's rheological model. If it is propagated to the side of larger elongation, then it tends to reach the ultimate (maximum) stress σ_U =525.47 kPa.

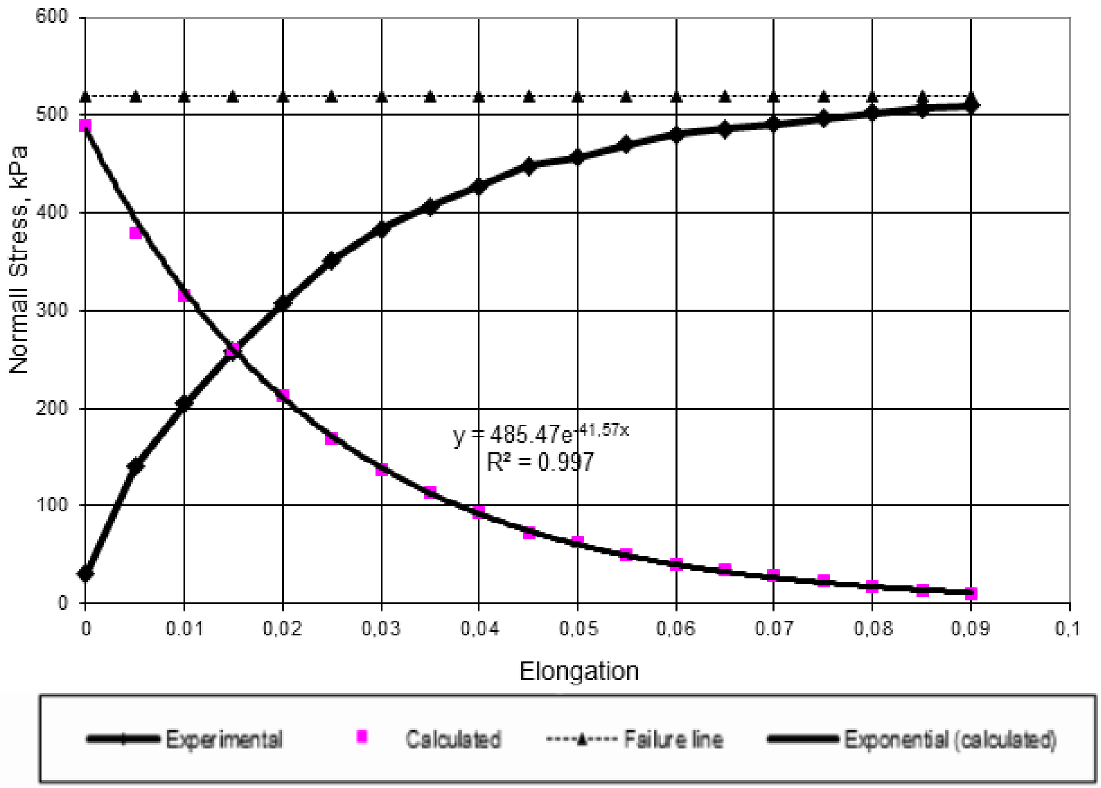

Figure 2. Dependence of normal stress on the elongation at the humidity of dried specimen of 22% and temperature of 75 °C

The ordinates of the calculated dependence were obtained by the following equation:

$$y_i = y_{1_i} - y_{2_i} - \sigma_T \tag{2}$$

where y_{1_i} are the ordinates of the failure line (σ_F =525.47 kPa);

The calculated dependence was processed by plotting the trend line yielding the exponential dependence of the form $y = A \cdot e^{-B \cdot x}$. In this case, A = 485.75, B = 41.57. Considering that the rheological properties of macaroni semi-products are described by eq. (1) we get: $A = \dot{\varepsilon} \cdot \eta_T$, from this, we have the viscosity at axial flow $\eta_T = \frac{A}{\dot{\varepsilon}} = \frac{485.47}{0.167} = 2907 kPa \cdot s$. The elasticity modulus at linear strain is derived from $B = \frac{E}{\eta_T \cdot \dot{\varepsilon}}$, so $E = B \cdot \eta_T \cdot \dot{\varepsilon} = 41.57 \cdot 2907 \cdot 0.167 = 194.41 kPa$.

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4. Conclusion

The design of the automatic device elaborated by the authors allows rapidly determining the structural and mechanical properties of macaroni semi-products (tensile yield stress, elasticity modulus at linear strain, viscosity at axial flow), which will appreciably accelerate the study of the cracking processes during their drying to develop the regimes of stable manufacturing of high-quality products.

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