Research of structural and mechanical properties of molded macaroni foods as a cutting object

Nasillo Urinov*, Lyudmila Dubrovets, Ibodullo Sohibov and Rayim Isamov
Bukhara Engineering-Technological Institute, Bukhara, Uzbekistan

*E-mail: urinov1960@mail.ru

Abstract. The article covers the influence of structural, mechanical and frictional properties of raw macaroni food on technological process of cutting. The characteristics of the friction of the working bodies of cutting equipment on semi-finished product being processed, i.e. the dependence of the friction force and the coefficient of friction have been determined.

1. Introduction
Complex physical and chemical, biological and mechanical processes, the study of which allows organizing effective and objective quality control and management of technological cycle of production, accompany processing of various food materials.

Rheology and rheological methods have been widely developed in study of structural and mechanical properties of various materials, in solving problems related to plasticity, creeping and physical-chemical mechanics of materials, as well as in solving various technological problems. Fundamental works on the rheology of dispersed systems and physical-chemical mechanics facilitated this. The complex of physical and mechanical properties of food products includes friction and adhesion properties, the importance of which in various technological processes is extremely high. A.S. Akhmatov, G.V. Bartenev, B.V. Deryagin, I.V. Kragelsky, V.D. Kuznetsov and others studied the general regularities of the phenomena of external friction, taking into account the adhesive component. Let us go into detail on the study of these properties.

A bunch of raw macaroni tubes is a very specific and complex subject of study, because its deformation and strength properties simultaneously depend on the complex of properties of the initial material – macaroni dough, the peculiarities of the geometric shape of the tubes, the parameters of their laying and the behavior of each tube in the bundle.

Structural and mechanical properties of raw macaroni are determined by a combination of the technological characteristics of initial raw material, the batch formulation and the conditions for the manufacture of products.

When pressing macaroni dough, orientation of large and small starch grains in the microvolume of gluten gel occurs, which determines their dense “package” of the structure, and the displacement of elementary layers relative to each other is accompanied by disorder of the integrity of starch grains. Under the action of the pressing pressure, the proteins are compacted, as well as hydration, elasticity and extensibility decrease. These changes in the properties of gluten have a decisive effect on the strength and plastic properties of the dough.
The strength and plasticity of macaroni dough under certain conditions can be in dynamic equilibrium. The strength of a dough made from normal quality macaroni flour does not depend on the amount of opposite pressure. The strength of raw products increases as the opposite pressure increases. When processing bakery flour, the amount of opposite pressure affects not only the strength of the products, but also their plasticity; with an increase in the opposite pressure, the plasticity decreases, and the strength increases [1].

2. Methods
Let us consider the influence of structural, mechanical and frictional properties of raw macaroni products on cutting process. Industry experience has shown that excessively wet shaped tubes make cutting difficult. They are deformed, crumpled. Cut quality deteriorates, products lose their shape, and drier products break, which requires additional costs and lengthens the production cycle of finished products.

Various processes of mechanical processing of food raw materials and products are inseparable from friction. Knowledge of parameters characterizing the frictional interaction of raw macaroni products with working bodies of cutting machines is necessary for the correct calculation of equipment and a reasonable choice of structural materials [2].

A.D. Zimon [3] carried out a deep study of the theoretical and practical aspects of the adhesion of various food half-finished products.

Analysis of literature data shows that the frictional and adhesive properties of bakery dough have been studied in great detail in the works of Yu.A. Machikhina, V.A. Andrianova, V.N. Danilova, O.G. Silaeva, V.S. Ivanova, S.M. Kalinina and other authors [4, 5]. At the same time, it should be noted that similar studies of macaroni dough were carried out only for molding conditions in a limited range of speeds and pressure [6].

The influence of the microgeometry of working surfaces and blowing parameters of pressed macaroni strands on indicators of the friction and adhesion properties of half-finished product has practically not been studied. The purpose of implementation is to determine the characteristics of friction of the working bodies of the cutting equipment for the processed half-finished product in relation to the choice of rational modes of their operation.

To achieve this purpose, a disk-type tribometer was developed and manufactured, which is shown on figure 1.

The working elements of the tribometer are a rotating disc 3 and a stationary disc 4, which is hinged on the rod 7. A thin layer (2 mm) of macaroni dough is placed between the friction surfaces of the discs. The pressed circuit is regulated by replaceable weights 5. On the rod 7 a strain bar 6 is rigidly fixed, on which strain gauges are glued. Direct current motors 1 and worm gear 2 transfer rotation to disk 3, which is rigidly mounted on the gearbox shaft.

The rotational speed of the drive disk is regulated by varying the voltage. When the disk 3 rotates between it and the dough pressed by the disk 4, a friction moment arises, which is transferred by the rod 7 to the strain gauge beam 6. Deformation of the strain gauge bar leads to unbalance of measuring bridge of the strain amplifier 8 of the TA-5 brand, the output signal of which is recorded on the recorder tape in units of force. This determines the magnitude of the sliding friction force of the surface of the macaroni dough over the surface of the disc made of the material under study.
The friction force between the driving and driven disks of the device was determined by the formula:

$$F_T = P \frac{l}{R_{np}}$$

(1)

where $P$ is effort on the lever; $l$ is the length of the lever arm; $R_{np}$ is the reduced radius of the contact area with the disk

$$R_{np} = 2 \left( \frac{R_H^5 - R_B^5}{3 \left( R_H^2 - R_B^2 \right)} \right)$$

(2)

$R_H$ and $R_B$ are the outer and inner radii of the friction surfaces of the disks respectively.

The friction coefficient in accordance with the Hammonton-Coulomb law is

$$f = \frac{(F_T - A)}{N}$$

(3)

where $F_T$ is friction force; $A$ is shear adhesion force; $N$ is normal strength.

The $A$ value is determined by graphical extrapolation of $F_T = f(N)$ until relationship it intersects the ordinate. The segment, the difference between these axes, is equal to $A$ (figure 2). A significant difference of this method in comparison with those used earlier is the determination of the friction coefficient taking into account the shear adhesion force.

3. Results

The experiments carried out show that the adhesion force depends on the sliding speed and decreases with an increase in the speed from 0.117 to 0.22 m/s.

Figure 1. Schematic diagram of disk-type tribometer: 1 - electric motor; 2 - worm gear; 3 - rotating disk; 4 - stationary disk; 5 - cargo; 6 - strain gauge; 7 - rod, 8 - amplifier; 9 - recorder.

Figure 2. Dependence of the friction force on the magnitude of the normal load: 1- $U=0.117$ m/s; 2- $U=0.175$ m/s; 3- $U=0.22$ m/s; 4- $U=0.25$ m/s.

Figure 3. Dependence of the coefficient of friction on the duration of blowing: 1- W=29%; 2- W=30%; 3- W=31%.
When the speed increases to 0.25 m/s, the straight-line extrapolation of the dependence $F_T = f (N)$ is violated and the adhesion force tends to zero. This shows that at high sliding speeds, the contact time is reduced and the sticking of the dough is reduced to a minimum.

From the graph of the dependence of the coefficients of friction it can be seen that their value is largely determined by the sliding speed.

The dependence of the friction coefficient can be seen that their value is largely determined by the sliding speed has an extreme character with a zone of minimum $f$ at $U=0.16-0.18$ m/s (figure 3). This character is most clearly manifested for large values of $\sigma_K$. The fall of $f$ in the initial range of speed variation is, in all likelihood, associated with a decrease in adhesion, as was established earlier (figure 2). The subsequent increase in the coefficient of friction can be explained by an increase in its interaction between the test and the counter-body [7].

The dependence of the friction coefficient on the value of the normal pressure is much more varied (figure 4). An increase in $\sigma_K$ practically does not affect the value of $f$ at $U = 0.117$ m/s (curve 1). However, the change in speed towards an increase manifests itself first in the form of a falling (curve 2), and then an increasing (curve 3) dependence.

The Fisher criterion was used to compare the adequacy of various approximating models: linear, quadratic, exponential, power. For all studied dependences, the highest value of the F criterion had a quadratic regression equation: $y = a + bx + cx^2$, the corresponding values of the empirical coefficients are presented in tables 1 and 2.

Table 1. Dependence of friction coefficients on pressure 4.63$<\sigma<$11.6 kPa.

| Coefficient | At sliding speed $u$, m/s |
|-------------|--------------------------|
|             | 0.117                    |
| A           | 0.515                    |
| B           | -0.031                   |
| C           | 0.002                    |

| Coefficient | At sliding speed $u$, m/s |
|-------------|--------------------------|
|             | 0.145                    |
| A           | 0.416                    |
| B           | -0.006                   |
| C           | -0.0005                  |

| Coefficient | At sliding speed $u$, m/s |
|-------------|--------------------------|
|             | 0.175                    |
| A           | 0.468                    |
| B           | -0.021                   |
| C           | 0.00001                  |

| Coefficient | At sliding speed $u$, m/s |
|-------------|--------------------------|
|             | 0.20                     |
| A           | 0.545                    |
| B           | -0.036                   |
| C           | 0.002                    |

| Coefficient | At sliding speed $u$, m/s |
|-------------|--------------------------|
|             | 0.22                     |
| A           | 1.00                     |
| B           | -0.163                   |
| C           | 0.012                    |

Table 2. Dependence of friction coefficients on sliding speed 0.117$<u<$0.22 m/s.

| Coefficient | At pressure value $\sigma$, kPa |
|-------------|---------------------------------|
|             | 4.63                           |
| A           | 1.16                           |
| B           | -10.1                          |
| C           | 32.6                           |

| Coefficient | At pressure value $\sigma$, kPa |
|-------------|---------------------------------|
|             | 6.37                           |
| A           | 1.03                           |
| B           | -8.41                          |
| C           | 25.61                          |

| Coefficient | At pressure value $\sigma$, kPa |
|-------------|---------------------------------|
|             | 8.11                           |
| A           | 1.39                           |
| B           | -13.16                         |
| C           | 39.85                          |

| Coefficient | At pressure value $\sigma$, kPa |
|-------------|---------------------------------|
|             | 9.85                           |
| A           | 1.97                           |
| B           | -20.37                         |
| C           | 61.05                          |

| Coefficient | At pressure value $\sigma$, kPa |
|-------------|---------------------------------|
|             | 11.6                           |
| A           | 3.22                           |
| B           | -37.10                         |
| C           | 114.4                          |

Figure 4. Dependence of the friction coefficient from a) sliding speed 1-$\sigma_c=4.63$ KPa; 2-$\sigma_c=6.37$ KPa; 3-$\sigma_c=8.11$ KPa; 4-$\sigma_c=9.85$ KPa; 5-$\sigma_c=11.6$ KPa. b) value of normal pressure 1 $U=0.117$ m/s; 2 $U=0.175$ m/s; 3 $U=0.22$ m/s.
A decrease in the adhesion properties of molded macaroni during cutting in production conditions is achieved by blowing. When studying the effect of blowing on the change in the coefficient of friction, an installation made according to the type of production units 16 and consisting of a low-pressure fan and a system of air ducts has been used.

4. Discussion
For the experiments, we used a macaroni dough with a moisture content of 29-31%. Before placing the sample in the tribometer holder, the dough surface was blown off. In this series of experiments, the constant parameters were contact voltage equal to 8.11 kPa, surface roughness of the counter-body Ra 6.3 according to GOST 2789-63, sliding speed 0.175 m/s, air temperature 25 °C. In this series of experiments, the duration of blowing and dough humidity were changed.

The research results showed that the dependence of the friction coefficient on duration of blowing for dough with different humidity has the form of falling exponentials. In the first 5 s of blowing, the friction coefficient decreases by 2 times, and then, after 10 s of blowing, the value of f characterizes the friction of the dried dough surface formed by blowing.

At the same time, if for half-finished product without blowing the value of f significantly depends on its initial moisture content, then after blowing for 15-20 s, the friction coefficient for all samples of macaroni dough stabilizes at a level of $f \approx 0.2$. The use of the above calculation methodology shows that adhesive component sharply decreases in the latter case.

5. Conclusions
Structural, mechanical and strength properties of a layer of raw macaroni tubes depend on complex of technological rheological properties of macaroni dough, molding conditions, features of the geometric shape of the half-finished product and the density of their laying in the layer.

Adhesion component of friction decreases with increasing sliding speed. The friction coefficient of macaroni dough on polished steel surface has a minimum zone in the speed range $U=0.16-0.18$ m/s. Blowing significantly reduces the value of the friction coefficient, which, with an increase in its duration over 10 s, asymptotically approaches to 0.2 value.

References
[1] Romanenko Yu V and Khamitov R I 1981 Optimal parameters of knife at vibration cutting of candy strands Confectionery industry 9 23-7
[2] Urinov N F and Khromeenkov V M 1991 Experimental characteristics of frictional interaction of macaroni dough with the working bodies of cutting equipment Proceedings of the VIII Conference of young scientists and specialists, dedicated to the 60th anniversary of formation of MTIFI pp 126-8
[3] Medvedev G M 1984 Technology and equipment for macaroni production (Moscow: Light and food industry) p 280
[4] Kragelskiy I V 1968 Friction and wearing (Moscow: Mashgiz) p 583
[5] Ivanov V S, Kalinina S M and Machikhin Yu A 1990 The role of dough surface properties in the production of bakery products Central research institute of information and technical and economic research MHP USSR p 41
[6] Machikhina Yu A 1990 Rheometry of food raw materials and products: Handbook (Moscow: Agropromizdat) p 271
[7] Lebedev Yu A 1975 Research of work and development of dough-forming elements (Abstract of candidate’s dissertation) p 24