Impact of microgeometric parameters on the sliding cutting behavior of macaroni products

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Abstract. The primary objectives of the food industry sectors in the Republic of Uzbekistan are to intensify and optimize technological processes, adopt new progressive equipment for efficient processing modes, reduce energy costs and raw material losses, and improve product quality. Accordingly, this article presents a solution to one of the problems and provides an analysis of the cutting ability of the tool based on the investigated set of blade microgeometry parameters. The research aims to determine the numerical values of the microgeometry parameters for lamellar knife blades, obtained through various formation methods, and to identify the nature of their changes during operation. Additionally, the study explores the possibility of achieving such blade microgeometry parameters during sharpening, which were obtained through the optimization of the cutting ability objective function. The system described in the article has been implemented using the method of microscopic examination of lamellar knives, which allows for the photography of the blade surface and facets, contributing to the visual control of the cutting-edge condition immediately after its formation and during operation.

1 Introduction

The microgeometry of the cutting part of the knife-blade has the great significance in the sliding cutting the molded raw macaroni products.

After sharpening, the cutting edge has many microscopic teeth and cavities of various heights, through which the process of introducing and cutting the material is carried out. The study of the shape of microroughness dimensions, the determination of their effect on the operational properties of the cutting tool using traditional methods of research (using profilographs, profilometers, etc.) does not give high accuracy of the results due to the design features of the knife, namely: small transverse dimensions (10-500 microns) and high sharpness of the cutting edge [1].

Research conducted in the field of studying the microgeometry of the cutting tool [2-4], showed that the longitudinal and transverse microrelief of the cutting edge can be most fully assessed using the following groups of parameters:

- height parameters characterizing the sizes of microteeth along the normal to the reference base;
- step parameters characterizing the distance between irregularities;

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- width of the cutting edge;
- structural parameters describing the structure and shape of microteeth.

Analytical instruments designed to study objects with sizes of the micron and submicron order must have adequate capabilities. Today, there are a number of traditional methods for studying surfaces: contact, based on mechanical probing of the surface with indicator and transmitting the vibrations of the latter to a sensitive sensor, and non-contact, the essence of which is to create a wave field of a different nature near the surface under study (electromagnetic, ultrasonic, etc.) and further analysis of its characteristics.

Raster electron microscopy makes it relatively easy to conduct qualitatively new microscopic studies [5, 6]. The operation of raster electron microscope (REM) is based on the television principle of scanning a thin beam of electrons or ions that scan over the surface; on the surface under study, physical phenomena are caused that are recorded by the corresponding sensors, and the signal from them, after amplification, models the local brightness of the kinescope. The kinescope scan is synchronized with the displacement of the primary beam. Therefore, each element of the surface of the research object is in one-one correspondence with the brightness of a certain place on the screen.

Today, a number of methods for quantitative analysis of the shape and structures of individual microobjects have appeared which use such operating modes of REM as the mode of transmissive and elastically reflected electrons (ERE) and the mode of secondary electrons (SE). The possibility of obtaining an information signal in analog form allows its subsequent processing on a computer.

2 Materials and methods

The purpose of research is designated as improving the quality of cutting raw macaroni products. Thereof, the following tasks have been solved: studying the shape of the size of the microroughness of the knife blade, determining the main characteristics that affect the accuracy of the shape of products of the micron and submicron order, increasing the operational properties of the cutting tool.

The work was carried out in the laboratory of electron microscopy of Institute of mechanics of metal-polymer systems of the Academy of Sciences of Republic of Belarus. The method for estimating the parameters of microgeometry of knives is implemented on REM - microcomputer complex, a general view of which is shown in Figure 1.

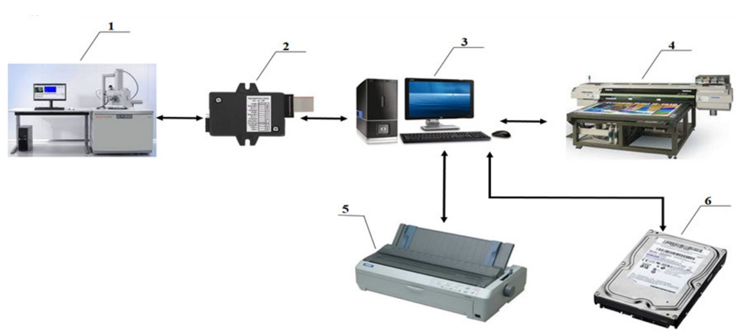

Fig. 1. General view of the complex for controlling microgeometric parameters of thin lamellar knives. 1-raster electron microscope (REM); 2- interface block; 3- electronic computer; 4- plotter; 5- matrix printer; 6- data storage.

Computer 3 (“IBM” PC) exchanges information with REM 1 (ISM 50 A) through interface unit 2, which contains analog-to-digital converter for inputting an image into a computer, digital reamer generator that controls reamer of the probe and a REM display, a digital-to-analog converter for output results, a control circuit for synchronizing the complex and software switching of the operating modes of the REM. The complex contains a number of peripheral devices: a plotter 4, a dot matrix printer 5 for outputting sign information and pseudo-images, a floppy disk drive 6.

Considering the above set of blade microgeometry parameters and the results of a theoretical analysis of cutting ability, we recorded the following parameters:

- for the first group:
  - the largest height of the profile irregularities Rmax, the arithmetic mean deviation of the profile Ra, the largest height of the protrusion of the smoothing depth RP.
  - for the second group:
  - longitudinal pitch along the midline Sm and transverse microprofile pitch Sn.
  - for the third group:
  - width of the cutting edge a.
- for the fourth group:
  - parameters в and ν of the reference curve.

To implement the described method, an application package was used, including:

- determination of the initial data of the profile of the working surface of the knife in the selected section;
- calculation of roughness parameters and moments of spectral density (ST SEV 1156-78);
- organization and presentation of the results of the analysis.

The described system of microscopic examination of lamellar knives allowed photographing the surface of the blade and facets, which contributes to the visual control of the state of the cutting edge immediately after its formation (T=0) and during operation (T>0).

3 Results of research

Figure 2 shows a micrograph of a sharpened blade at x1500 magnification. Dihedral sharpening of the knife was carried out with an abrasive wheel brand 24ASM1K5 with the parameters indicated above. The dark band in the middle of the blade shows the pit between two parallel rows of micro serrations. Light surfaces correspond to the side edges of the knife.

Fig. 2. Micrograph of a sharpened blade (x1500).

Figure 3 and 4 show micrographs of knife blades that have been in operation for 4 and 48 hours, respectively. From these photographs it can be seen that at T=4 hours the cutting edge has a significant number of micro-teeth located with a small longitudinal step. The width of the cutting edge, the transverse and longitudinal steps of the microrelief increase with an increase in the duration of the cutting tool.

Fig. 3. Longitudinal microprofile of the blade (T=4h).

Fig. 4. Longitudinal microprofile of the blade (T=48h).

Analyzing the micrographs shown in Figure 5 and 6, one can see the nature of the effect of finishing on the microrelief of the blade. Common to these samples is that the risks (microgrooves) are elongated in the direction of movement of the microcutting elements - the grains of the abrasive wheel. The relief in the longitudinal and transverse directions is significantly different. Figure 5 shows part of the facet and the blade processed according to mode 1 (Table 1). The sharpening of this sample was carried out in the direction parallel to the blade, which can be seen from the nature of the orientation of the microgrooves. The grooves differ in a certain depth and, if the direction of sharpening is fixed, they can undercut the blade and thereby reduce the bone properties.

Figure 6 shows a decrease in the contrast of the image, which indicates a change in the height and angular parameters of the microrelief. This sample corresponds to the blade, finished after sharpening mode 4 (Table 1). The finished blade has the same microgroove

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pitch, but the tooth height is much smaller. At a high magnification (x3000), microphotographs of the blade after finishing (Figure 7) show pronounced microteeth located almost in one row with a small longitudinal step

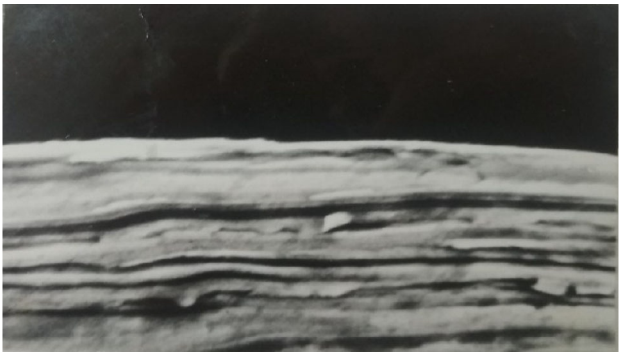

Fig. 5. Micrograph of the blade after sharpening in parallel cutting edge (x1500).

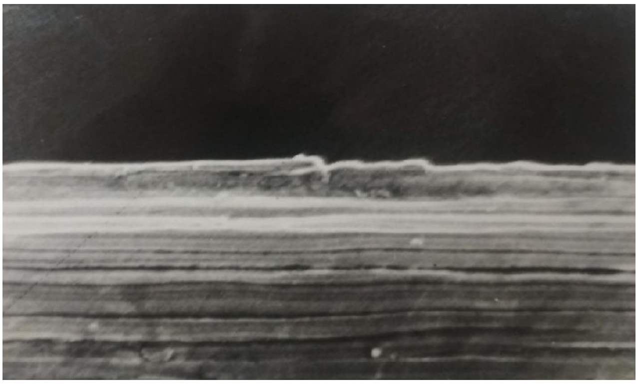

Fig. 6. The effect of finishing on the microcharacteristics of the blade (x1500).

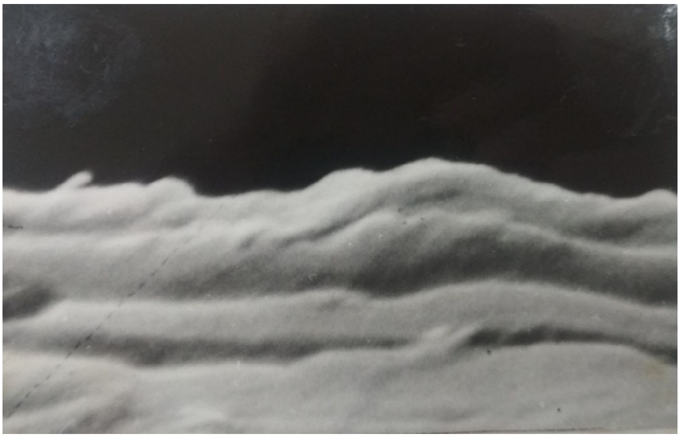

Fig. 7. Micrograph of blade section at high magnification (x3000).

Therefore, application of REM-ECM measuring complex allows determining the selected characteristics of the cutting edge of knives with a high degree of accuracy and efficiency.

The conducted microgeometric studies of the cutting edge of the knives confirmed the validity of the assumptions made.

4 Research results

The state of the surface of the cutting edge largely determines the operational properties of knives: cutting ability and durability period, resource and quality of cut products.

Parameters of the macro and microgeometry of the blades are formed at the stage of sharpening the tool [7], and then change their value during the operation of the cutting machine. In addition, the possibility of achieving such blade microgeometry parameters during sharpening, which were obtained because of optimization of the cutting ability objective function, have been studied.

It can be assumed that the reduction of cutting forces due to the optimal microgeometry of the blades, in addition to improving the quality indicators of the process, will also increase the life of the cutting tool.

In this section, the objects of microscopic examination were lamellar knife blades (δ=0.4mm) of U8A tool steel that heat-treated to the hardness of 46-48 HRC. The angle of double-sided sharpening was 15°. The grinding was carried out on the machine of 3G71 model with a circle 24ASM1K5 without lubricant with a wheel dressing with a C-type diamond pencil. Lapping (finishing) of the facets was carried out using diamond ink. The parameters of initial sharpening were: grinding speed - 30 m/s; grain size of the abrasive wheel 10-40 microns; speed of movement of a detail 6 m/min; grinding depth 0.01mm.

The results of measurement of the parameters of the microgeometry of lamellar knives are given in Table 1. The samples shown in the first column under the numbers 1,2,3, etc., were obtained at the following conditions: 1- knife facet grinded at the above parameters; 2- blade of the mentioned sample; 3- sharpening and finishing of the blade on one edge; 4- sharpening and finishing of blade on two sides; 5-sharpening according to type 1 after 4 hours of work; 6- sharpening according to type 1 after 48 hours of work; 7- sharpening and finishing according to type 7 after 48 hours of work.

Sharpening without grinding gives the width *a* of the cutting edge and the transverse step S_n, which is several times greater than a blade brought along 2 edges. This is shown in the micrograph (Figure 2), where the dark strap corresponds to the width of the cutting edge, and the microteeth are arranged in two parallels with the distance S_n between them. As the finishing progresses, the micro teeth gradually line up along the blade. In this case, the parameters *a* and S_n decrease by 3-4 times.

Table 1. The results of measuring the parameters of the microgeometry of lamellar knives.

No.	**a micron**	**Ra micron**	**Rp micron**	**Rmax micron**	**Sn micron**	**Smax Micron**	**в -**	**ν -**	**γ -**
1	2	3	4	5	6	7	8	9	10
1	-	2.37	4.3	9.2	-	16.3	2.3	1.8	40
2	18.3	7.93	11.8	23.2	11.2	79.1	2.5	3.2	42
3	12.9	5.62	9.3	19.8	7.1	115.1	1.8	3.0	40
4	4.6	3.25	4.7	12.4	2.8	175.8	1.1	0.75	38
5	21.6	5.81	11.0	24.3	10.4	263.2	2.0	1.8	53
6	31.3	12.2	19.5	29.0	17.3	721.0	1.8	2.2	69
7	14.3	5.37	10.0	21.7	7.9	380.0	1.2	1.1	48

Between changes in the values of *a* and *Sn* with varying modes of blade formation and duration T of knife operation, there is a one-one correspondence. The same can be stated with respect to the group of altitude parameters.

The microteeth R_{max} on the blade has the maximum height 2-2.5 times higher than on the facet. This, in our opinion, is explained by the superimposition of the two microreliefs on the blade, which are formed apart during facet grinding. Then, when the knife is working ($T>0$), the value of R_{max} additionally increases by 15-40%. These changes in R_{max} cannot cause an increase in cutting power, because these microteeth are formed on a wider blade.

The value of the longitudinal step S_m of microroughness of the blade is an order of magnitude higher than the value of S_n. On the other hand, S_m on the facet is 5-8 times less than on the cutting edge. The use of finishing on one and two facets contributes to an increase in S_m, which should contribute to an increase in the cutting ability of the blades. During the operation of knives, S_m increases, the growth of S_m (almost 10 times) is especially noticeable for knives sharpened without finishing (sample No. 1).

As can be seen in Table 1, the coefficients *в* and *ν* of the bearing surface curve vary in a wide range from 1.1 to 2.5 (for *в*) and from 0.75 to 3.0 (for *ν*). Values close to optimal were recorded for samples No. 4 and No. 7.

Values of the contour angle γ for sharpened and finished blades are less than 45°, and for blades that have worked for 48 hours are more than 45°. This is in good agreement with the assumptions made in the theoretical analysis of cutting ability.

Research has shown that the grinding of the microgeometry of the cutting edge mainly occurs because of the intersection of the microreliefs of the side surfaces, and the microgeometry is influenced by not only the physical-mechanical properties of the material and the technological parameters of sharpening, but also by the forces and direction of grinding. Therefore, after grinding, finishing operations are needed.

Analysis of the data given in Table 1 showed that there is a consistent decrease in the roughness of the cutting-edge during finishing on one and two faces. Therefore, the height parameters of the cutting edge are reduced by 1.8-2.0 times after finishing on two faces.

Finishing along one face can cause distortion (bending) of the edge vertices due to processing forces. With double-sided processing, the geometry improves.

Finishing significantly increases the period of resistance of the knife. After 48 hours of work, the sharpened knife had a cutting-edge width of 21.6 microns, and the finished one had 30% less. It is also necessary to note significant changes in S_m: for sharpened blades after 48 hours of operation, the value of the longitudinal step is about 720 microns, while for a sharpened blade it is almost two times less ($S_m \cong 380$ microns).

Other parameters (R_a, R_p, R_{max}, S_n) depend on finishing and duration of work to a lesser extent. Finishing on two edges provides the sharpest blade (width of the cutting edge a = 4.6 micron) and the minimum transverse step S_n.

A series of experiments was carried out with optimal kinematic parameters determined empirically: $2n$=20 Hz; S=15 mm.

During a preliminary series of experiments, an almost directly proportional relationship between the moisture content of the half-finished product and the cutting ability Q. Therefore, in the main series, a half-finished product with a moisture content W=30% was used, the blowing time was 3 s. Considering the results of the experiments, the value of R2 was taken equal to 5 N. In the experiments, knife samples with microgeometry parameters corresponding to the data in Table 1 were used. The characteristics of the cutting ability Q and quality indicators of K_I are given in Table 2.

Table 2. The characteristics of the cutting ability of the knives.

Parameters	Knives samples						
	1	**2**	**3**	**4**	**5**	**6**	**7**
$U_2 \cdot 10^2$, m/s	-	1.8	1.9	2.2	1.6	1.6	2.1
Q	-	0.27	0.28	0.35	0.26	0.26	0.32
K_1	-	0.93	0.94	0.98	0.95	0.95	0.97

There is single-valued relationship between the values of U_2 and K_1: large values of U_2 correspond to large values of K_1 and vice versa. Initially, it could be assumed that when researching in the R_2=*const* mode, the different cutting ability of the knives should not affect the value of K_1, since the deformation of the layer during cutting is carried out under the same conditions. However, an increase in the duration of cutting when using some samples (No. 2,3,6) causes a greater number of cycles of impact of the sides of the cutting tool when cutting a certain height of the layer of tubes, which, given their plastic properties, causes shape distortion.

Sharpening with subsequent finishing along two edges (sample No. 4) corresponds to obtaining the highest cutting ability.

Such a knife retains its cutting ability for a very long time, which is most likely due to the hardening of the microrelief elements due to work hardening during finishing. It should be noted that sample No. 4 after the formation of the blade (see Table 1) has the minimum value of the angle γ and the numerical values of the coefficients *в* and ν of the bearing surface curve, which are close to optimal. Even after 48 hours of operation, such a knife provides a coefficient K_I=0.97.

Comparison of the data in Table 2 with the results of optimization of the cutting ability shows that sample No. 4 is the most consistent with the theoretical data. However, it is technically impossible to obtain optimal characteristics simultaneously for all parameters of microgeometry (a, S_m, R_{max}, etc.) with the existing methods of forming a cutting edge (grinding and finishing). In all probability, in the future it will be possible to ensure optimal microgeometry characteristics for all 4 groups due to modern thin-film technologies, for example, vacuum ion-plasma processing.

5 Discussion

Numerous studies in this field focus on the technique of slicing food materials, where the width of the blade and the sharpening angle of the cutting tool play crucial roles in creating a new surface. V.P. Goryachkin highlighted the significance of the microteeth on the blade in determining the nature of material destruction and the quality of results in sliding cutting [8].

Researchers analyze various parameters to characterize the microgeometry of the cutting edge. Ivashko A.A. considers factors such as blade thickness, tortuosity, height of microcutting element protrusions, angle of inclination of microelement faces to the blade line, width of depressions between microelements, and the distance between blade tips [9].

The involvement of microteeth in sliding cutting, as suggested by several authors [10], closely mirrors the curve of the supporting surface. They recommend dividing the curved support surface into three sections and selecting optimal cutting tool sharpening parameters based on the characteristics of the second section, which represents the stable interaction of microteeth with the material being cut.

Sharpness, as described by O.A. Tsvetkov, encompasses the intricate geometric parameters that define the shape, dimensions, and manufacturing quality of the cutting edge [11]. The cutting ability signifies the blade's capacity to penetrate the material being cut, influenced by sharpness, material properties, cutting conditions, and process type. P. Isaev, I. Lebedev, and M. Semenov evaluate the cutting ability of a blade by the ratio of microroughness pitch (S) along the cutting edge to microroughness height (Ra). Their research indicates that initially, S/Ra = 2.5-3.0, increasing to 10-11 towards the end of the blade's lifespan [12].

M.N. Klimenko finds that blades with a smaller sharpening angle exhibit superior cutting ability, despite having significant microroughness height. These blades undergo rapid microgeometry changes during the initial break-in period. He highlights the optimal performance of blades with polished edges finished with microbars [13].

Conducting experimental studies on the impact of cutting tool microgeometry on cutting ability, and comparing experimental results with theoretical analyses, is crucial. Experiments were conducted under R_2=*const;* U_2=*var* conditions, using a cassette with molded tubes on a carriage moved along guides by rollers under load and a flexible thread over a block. O.P. Renzyaev's work provides a detailed method for assessing cutting ability in the R_2=*const* mode, with sample preparation and quality control procedures outlined for consistency [2].

6 Conclusion

Quality of cutting raw macaroni products under production conditions is quite reliably characterized by coefficients that consider deviations in the shape of the tube section from the circle (K_I) and its deflection (K_{II}), as well as a generalized indicator of shape accuracy (K). When choosing the optimal cutting parameters in laboratory conditions, it is advisable to use only the coefficient K_I

Research under production conditions showed insufficient accuracy and stability of cutting raw macaroni products a cassette production method. The value of the generalized quality index K is 0.5, which indicates the need to improve this technological operation.

Quality of the cut surface is characterized by the values of each component R_1 and R_2 of the total cutting force and the quality coefficients K_I and K_{II}. Increase in the value of R_1 and R_2, respectively, leads to the appearance of return waste and deformation of subsequent layers of wet tubes. The area of intersection of curves R_1 and R_2 can be considered as optimal cutting conditions. In this case, the total cutting force $R \longrightarrow min$, and the value of the coefficient K_I corresponds to the maximum ($K_I = 0.96 \div 0.97$).

Shaping of the microgeometry of the cutting edge occurs due to the intersection of the microreliefs of the side surfaces (facets). The numerical values of the parameters of the microgeometry of the blades, obtained by various methods of formation, have been determined, and the nature of their change in the process of work has been revealed. Finishing the blade reduces its width and the transverse pitch of microteeth by 3-4 times.

The highest cutting ability and durability are characteristic of knives, the blade of which, after sharpening, had a finishing along 2 edges. Such a cutting tool has microgeometry characteristics that are closest to the numerical values obtained because of optimization. The work of such knives provides the maximum value of the coefficient K_I.

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