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MECHANICS AND ENGINEERING

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INVESTIGATION OF THE HEIGHT PARAMETER OF ROUGHNESS BY THE METHOD OF MATHEMATICAL PLANNING OF THE EXPERIMENT DURING ABRASIVE BLASTING OF SAW BLADES

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Abstract:

Objective. Roughness of the flank surface of linter saw teeth when abrasive blasting with black carbide particles.

Methods. The method of full-factor mathematical planning of the experiment is applied.

Results. The regression equations are obtained, which make it possible to assess the degree of influence of the processing parameters on the height parameter of the surface roughness. As a result of abrasive blasting of linter saw teeth, a favorable micro-profile of their side surfaces was formed. Such a surface profile is able to enhance the contact interaction with the cotton fiber and to carry out its additional scraping from the seeds.

Conclusion. An intensification of the linting process has been achieved due to the activation of the lateral surfaces of the teeth of the roughly created surface with a certain step and height of the roughness.

Keywords: saw blade, abrasive blasting, experiment planning, unevenness of height, pressure, angle of attack, lintering.

Introduction.

High quality indicators of cotton processing during ginning and linting, first of all, are provided by the geometric parameters of the saw blade teeth and the condition of their working surfaces. At the same time, the cost of production (cotton fiber, lint, seeds) in the processing of raw cotton is largely determined by the durability and performance of saw blades, which are the most massive part of the working body of disks and linters. Consequently, the technological support of high efficiency of saws will allow for an effective solution of a number of particular problems (increasing the wear resistance of the saw blade teeth; improving the quality indicators of fiber during ginning; intensifying the linting process, etc.).

Saw blades made of U8G carbon tool steel (C - 0,80-0,90%; Mn - 0,33-0,58%; Si - 0,17-0,33%) and 65G spring steel (C - 0,62-0,70%; Mn – 0,8-1,2%; Si - 0,17-0,37%), are the main part of the working body (saw cylinder) of fiber separating machines - saw gins and linters. These heat-treated steels must meet the requirements for technical specifications for the manufacture of saw blades and have the following values of mechanical properties, respectively: hardness HRA 67-70 and 66-69; ultimate tensile strength σp=1150 and 980 n/mm^2.

As shown in studies [1-5], thermal hardening (laser beam treatment, electrical contact heating) of genie saw teeth, creating high hardness of the entire working part of the tooth tip, carries out volume hardening. However, this type of hardening is undesirable for parts subjected to alternating bending stresses, since it does not maintain the required core toughness of the part. Therefore, for the operation of saw blades that have even a high surface hardness, due to the lower resistance to bending of the teeth, their performance may decrease.

Saw teeth, which are subject to both fatigue failure and wear of contact surfaces during operation, must combine the viscous core of the working part of the tooth and sufficient surface hardness. Shot-impact treatment [6-8] (processing with microbeads) of saw teeth is a highly effective method of technological assurance of the quality of their surface layer, which has a positive effect on the durability of the processed products. This treatment refers to impact methods of surface plastic deformation of machine parts and provides mechanical strengthening (increase in microhardness) of the surface layer of saw teeth while maintaining the viscous core of the part. The advantage of shot-hammering is the creation of strain hardening and, at the same time, smoothing of the burrs on the transitional surface teeth after they are cut.

Expanding the technological methods of ensuring high efficiency of saw blades, it is necessary to point out the positive experience of using abrasive blasting of teeth of linter saws [9,10]. Depending on the size (grain size) of abrasive particles (silicon carbide, fused alumina, copper slag, etc.), it is possible to solve various technological problems associated with the formation of a given roughness, removal of burrs, creation of work hardening. Abrasive particles have many sharp edges that act as cutting wedges with different geometries and are capable of microcutting with the formation of surface microroughness on the workpiece [11,12].

The linting process [16,17], carried out by scraping the fiber material from cotton seeds with the sharp tip of the saw teeth, can be intensified if the flank surfaces of the teeth are also activated and involved, creating a purposefully controlled rough surface profile. It is necessary by abrasive blasting to obtain such a surface profile, in which the height of the irregularities and the pitch of their location will be commensurate with the fiber diameter.

Methods.

To establish the dependence of the height parameter of roughness on the operating parameters of abrasive blasting of linter teeth, experimental studies were carried out based on the mathematical method of experiment planning [13-15]. As input parameters (factors) were taken: pressure of compressed air p, atm; angle of attack of abrasive α, deg. Processing time – t = 2 minutes. The output parameter is the conditional roughness height H, microns. As an abrasive material, black silicon carbide (BSC) was used, which has high cutting properties and therefore is used in the manufacture of grinding wheels.

The levels and intervals of variation of factors obtained on the basis of preliminary tests and a priori information are shown in table 1.

table 1

Levels and intervals of variation of factors

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№ p.p	Factors	Codedesignation	Variationinterval	Factorlevels		
				upper +1	main 0	lower -1
1	airpressure p, atm	X_1	1	4	3	2
2	angle of attack of abrasive α, deg.	X_2	15	45	30	15

In the present study, a full factorial experiment was applied, in which all possible combinations of factor levels are implemented:

$$N = m^k, \tag{1}$$

Where m – the number of levels of each factor; k – number of factors.

Results.

In accordance with the data of experimental studies to determine the height of irregularities (Table 2), a regression equation with coded variables was obtained:

$$y = 1{,}85 + 0{,}15x_1 + 0{,}3x_2 + 0{,}25x_1x_2 \tag{2}$$

table 2

Planning matrix and test results

Experience number	X_0	X_1	X_2	X_1X_2	Y
1	+	-	-	+	1,6
2	+	+	-	-	1,4
3	+	-	+	-	1,8
4	+	+	+	+	2,6

The check of the static significance of the coefficients of the regression equation (2) was carried out by comparing the absolute value of the coefficients with the confidence interval.To determine it, the variance of the coefficients of the regression equation was preliminarily calculated through the variance of the reproducibility of the experiment (table 3) *table 3*

Auxiliary table for calculating the variance S_y^2 of the reproducibility of the experiment

№ experience	y_u (R, mcm)	$\bar{y}$	$(y_u - \bar{y})$	$(y_u - \bar{y})^2$	$\sum_{n=1}^{n_0}(y_u - \bar{y})^2$	S_y^2
5	2,1	$\frac{\sum_{n=1}^{3} y_u}{3} = 2{,}13$	-0,03	0,0009	0,0067	$\frac{\sum_{u=1}^{n_0}(y_u - \bar{y})^2}{n_0 - 1} = 0{,}00335$
6	2,2		0,07	0,0049		
7	2,1		-0,03	0,0009		

The coefficients b_1, b_2, b_{12} of the regression equation (2) are greater in absolute value than the confidence interval $\Delta b_i = \pm 0{,}124$ and therefore should be considered statistically significant. To test the hypothesis of the adequacy of the model (equation 2), we find the variance of the adequacy by the formula:

$$S_{\text{ad}}^2 = \frac{\sum_{j=1}^{N}(y_i - \hat{y}_j)^2}{f}, \tag{3}$$

Where y_j- is the experimental value of the optimization parameter in the j-th experiment; $\hat{y}_j$ is the value of the optimization parameter in the j -th experiment, calculated according to equation (3.8); f is the number of degrees of freedom, determined by the relation $f = N - (k + 1)$, where k is the number of factors equal to 2.

To compose the sum included in expression (3), we will compose an auxiliary table. 4. When calculating the values of $\hat{y}_j$, it is necessary to substitute the coded values of the factors into equation (2).

In accordance with formula (3), the variance of the adequacy was

$$S_{\text{ad}}^2 = \frac{0{,}01}{4 - (2 + 1)} = 0{,}01$$

The hypothesis of the adequacy of the model was tested according to the F-test of Fisher. To do this, we find the calculated value of the criterion

$$F_p = \frac{S_{\text{ad}}^2}{S_y^2} = \frac{0{,}01}{1{,}0289} = 0{,}346 \tag{4}.$$

With a 5% significance level and the number of degrees of freedom for the numerator $f_1 = 1$ and for the denominator $f_1 = 2$, the table value of the Fisher criterion is F_T=18,5. Since $F_p < F_T$, the linear model represented by equation (2) is adequate.

table 4

Auxiliary table for calculating the variance of adequacy S_{ad}^2

Experience number	y_j	$\hat{y}_j$	$y_j - \hat{y}_j$	$(y_j - \hat{y}_j)^2$
1	1,6	1,65	-0,05	0,0025
2	1,4	1,45	-0,05	0,0025
3	1,8	1,75	0,05	0,0025
4	2,6	2,55	0,05	0,0025

The coded values of the factors are associated with the following natural relationships:

$$x_1 = \frac{p - p_0}{\varepsilon_1} = \frac{p - 3}{1}; \qquad x_2 = \frac{\alpha - \alpha_0}{\varepsilon_2} = \frac{\alpha - 30}{15}, \tag{5}$$

Where p_0, α_0 – main levels of factors in natural terms; ε_1, ε_2 – intervals of variation of factors. Testing the hypothesis of the adequacy of the model according to F – Fisher's criterion showed that the linear model is adequate and the condition $F_p<F_T$.

Passing from the coded values of x_1 and x_2 factors to natural p (pressure) and α (angle of attack), we obtain the dependence of the conditional height of irregularities H:

$$H = 2{,}3 - 0{,}35p - 0{,}03\alpha + 0{,}017p\alpha,\ \mu\text{m} \tag{6}$$

Discussions.

Equation (6) is adequate and therefore can be used as an interpolation formula for calculating the height of irregularities in abrasive blasting of linter saw teeth. Figures 1 and 2 show, respectively, the calculated values of the height of irregularities H (µm) depending on the angle of attack α (deg) of abrasive particles and air pressure p (atm) during abrasive blasting of the side surfaces of the teeth of linter saws.

With an increase in the angle of attack from $\alpha=30^0$ to $\alpha=75^0$ the height of irregularities at a pressure of p=2 atm increases insignificantly: H=1,72...1,90 microns. With an increase in the force factor (pressure p), a significant increase in the height of irregularities is observed: H=2,04...3,75 microns. Even the minimum values of the height of irregularities from these ranges are an order of magnitude higher than the height of irregularities recorded by the atomic force microscopy [18], method on the lateral surface of the saw teeth without processing H=0,143 µm. This height of the bumps cannot have any effect on the gripping and holding capacity of the bumps. Very small average stepirregularities S=9 µm do not contribute to the placement between the irregularities of the cotton fiber, since the fiber diameter d is much larger than the roughness pitch.

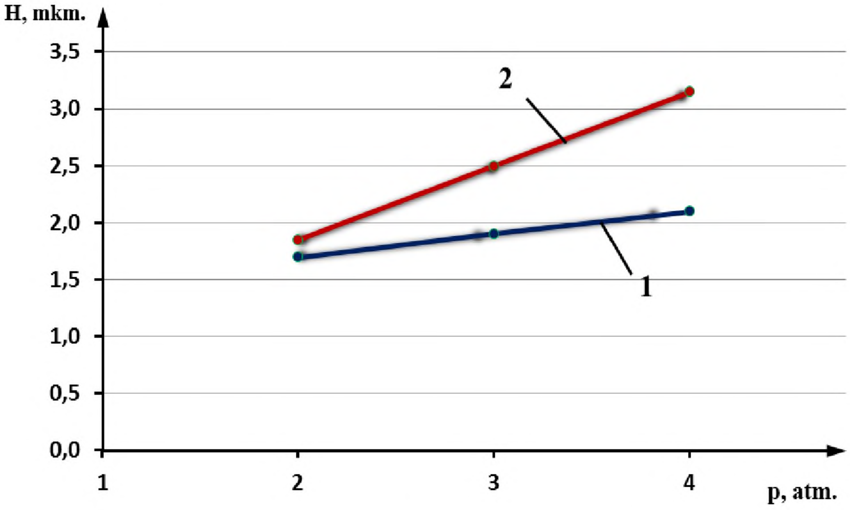

Figure.1. Dependence of the roughness height H on the angle of attack α during abrasive blasting of teeth of saw blades for linters

1 - air pressure p=2 atm; 2 - air pressure p=4 atm

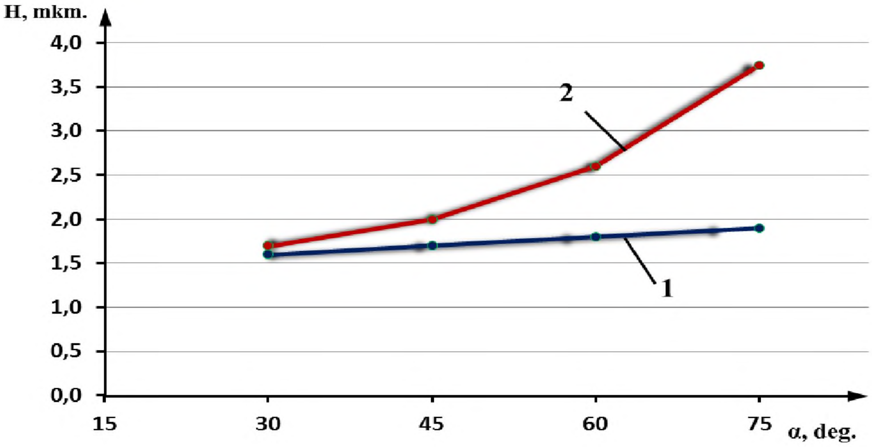

Figure.2. Dependence of the height of the unevenness H on the air pressure p during abrasive blasting of teeth of linter saws

1 - angle of attack $\alpha=30^0$; *2 - angle of attack* $\alpha=60^0$

Conclusion.

The main result of abrasive blasting of linter saw teeth is the formation of a favorable micro-profile with a large irregularity pitch S>20 µm, which serves as the basis for activating the flank surfaces of the saw teeth, since the condition is met: S>d (d=20 µm). Thus, abrasive blasting of the side surfaces of saw teeth, creating an appropriate surface micro-profile to intensify the linting process, simultaneously forms a hardened zone in a thin surface layer, as an inevitable result of elastic-plastic deformations during micro cutting with a hard abrasive grain. Therefore, not only the linting performance is improved, but also the durability of saws increases due to the increased wear resistance of the surface hardened layer of the saw blade teeth.

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PHYSICAL AND MECHANICAL PHENOMENA DURING ABRASIVE BLASTING OF WORKING SURFACES OF CRITICAL MACHINE

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Abstract:

Objective. The surface layer of the flank surfaces of the saw blade teeth after abrasive blasting.

Methods. The simulation of the interaction of abrasive grains and the metal surface of parts depending on the ratio of the cut thickness and the radius of rounding of the top of the abrasive particle.

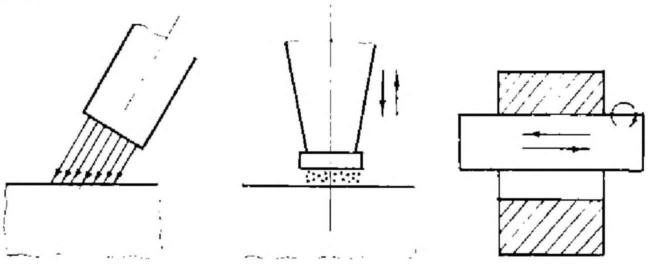
Results. The condition of the contact interaction of the abrasive grain with the processed surface of the part is obtained when microcutting occurs - scratching with the formation of detached microchips. This process can be easily accomplished by abrasive blasting with a sandblaster. In the process of abrasive blasting of the flank surfaces of the teeth of linter saws, a favorable micro-profile is formed, characterized by the height and pitch of irregularities. These roughness parameters, commensurate with the cotton fiber diameter, increase the linting efficiency.

Conclusion. Abrasive blasting of black teeth of linter saws with silicon carbide as a result of plastic deformation and microcutting creates a hardened layer and roughness parameters that contribute to the intensification of the linting process.

Keywords: abrasive blasting, abrasive, micro cutting, plastic deformation, surface roughness, saw blade, lintering.

Introduction.

Abrasive blasting of metal surfaces refers to the methods of machining machine parts with the removal of the allowance and can be considered as grinding with a free abrasive. A lot of abrasive particles, forming a stream, are directed to the surface to be treated at a certain angle α (angle of attack) due to the pressure p of compressed air or in the composition of an anti-corrosive liquid (waterjet treatment). Free abrasive processing is carried out by several methods (Fig. 1), used as finishing and hardening operations for critical machine parts in order to reduce roughness, create work hardening (strain hardening) and form favorable compressive residual stresses in the surface layer. The great advantage of the method of processing with free abrasive (under the pressure of a jet of air or liquid) is that the problem of finishing and hardening operations of volumetric curved and shaped surfaces is relatively easy to solve, when the use of conventional grinding methods is associated with great technological difficulties.



a) *b)* *v)*

Figure.1. Schemes of the main methods of free abrasive grinding:
a - jet; b - ultrasonic; v- finishing

When processing metal surfaces with a flow of free abrasives, both a decrease (smoothing) of the initial surface roughness with the appearance of a polishing effect and the formation of a coarser surface can occur, depending on the size of abrasive particles - grain size (grinding grain, grinding powders, micropowders) and initial surface roughness.In addition to the grain size of abrasive particles, the operating parameters and processing conditions also affect the quality of the processed surface of parts.

Natural abrasive materials (corundum, emery), consisting of Al_2O_3 and impurities, are not widely used due to their low mechanical properties. This group of materials also includes quartz sand.Of artificial abrasive materials, electrocorundum, silicon carbide (carborundum), boron carbide, cubic boron nitride, and synthetic diamond are widely used.

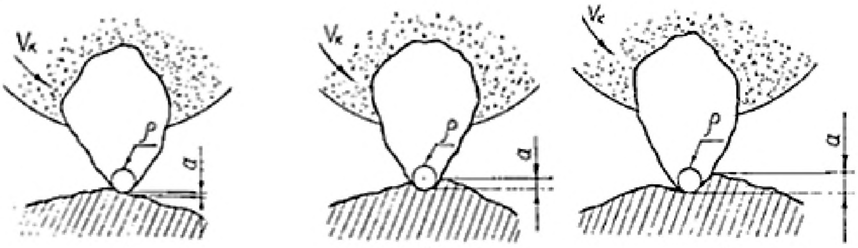
At present, a new abrasive material is increasingly used - kuperslag, consisting of FeO - 40-50%; SiO_2 - 25-35%; MgO - not less 5%; CuO - 6-10%. This abrasive material has the following characteristics: bulk density - 1,7 g/sm^3; basic granule size - 0,8 - 2,5mm - 83,5%; hardness on a scale Mooca - not less 6,0; dynamic strength factor - 13,3; abrasion coefficient - 4,4. The high abrasive ability and hardness of this material are able to provide the corresponding equipment (abrasive blasting machines) with operational reliability and productivity, the high-quality condition of the treated surfaces.The production of this abrasive material has been mastered in the Russian Federation (city Karabash, Chelyabinsk region).

Methods.

It is known that the grinding process has much in common with abrasive wear during friction, but there are a number of distinctive features: 1) the working surface of the tool is much rougher than the surface of the abrasive body; 2) grinding grains have high hardness, heat resistance and wear resistance with relatively high brittleness; 3) a high rate of metal removal per unit time, and the resulting chips during grinding are significantly larger in relation to wear products during friction.

Due to the fact that abrasive wear is a complex multifactorial process [1-5], it is necessary to systematize the schematic diagrams of the external force effect of the abrasive according to the main feature - the nature of the effect of an abrasive particle on the contact surfaces of wear of machine parts. As a basis for systematization, it is advisable to consider, first of all, the types of friction - sliding friction, rolling friction, impact of an abrasive with a metal surface, transformation of the geometric and physical-mechanical properties of the surface layer of a metal.So, for example, in sliding friction, the force interaction of a single abrasive particle with the wear surface is close to when, instead of a separate abrasive particle, a certain protrusion can be adopted, simulating the case of the particle fixing on the contact (grain on the grinding wheel).

Fundamental research by I.V. Kragelsky [6-8] showed that the interaction of metal surfaces has a dual molecular-mechanical nature and is realized at the touch spots through the appearance and disappearance of frictional bonds.In accordance with the universal classification of friction links developed by him, five main types of bond breakdown are distinguished: microcutting, plastic pushing back, elastic pushing back, seizure (adhesion) of surface films and their destruction, seizure of the base material and deep pulling out.The versatility of this classification consists in combining all types of wear from abrasive to atomic-molecular. Depending on the ratio of the cut thickness and the rounding radius ρ of the top of the abrasive particle (grain) during the working movement of the grain, the following actions can occur: sliding, plastic displacement and microcutting - scratching (Fig. 2).



a) *b)* *v)*

Figure. 2. Interaction of abrasive grains and workpiece surface: a) sliding of grain on the treated surface ($a \le \rho$); b) plastic repression ($a < \rho$); v) microcutting - scratching ($a \ge \rho$)

During microcutting, detaching chips arise and a scratch is formed with plastically squeezed piles on its periphery. Thus, the main mechanism of abrasive wear is that newly applied scratches on existing piles that are in a pre-fractured state (microcracks, tears, low hardness and strength) cause their destruction with the separation of metal particles.Therefore, abrasive wear can be relatively easily estimated in the form of weight loss (Δm) or volume (ΔV).

Results.

The occurrence of microchips during scratching significantly distinguishes this process from simple plastic deformation. Therefore, scratching is associated with plastic deformation and fracture. At the same time, the role of friction in the process of microcutting or scratching is extremely huge, since the friction force reflects the quantitative and qualitative picture of the mutual sliding of the surfaces of two solid bodies and affects the process of surface destruction, which is expressed by the wear of mating bodies. The work of the friction force includes the work of plastic deformation, hysteresis losses of elastic deformation and the work of dispersion [9-11], i.e. work related to the formation of new (juvenile) surfaces and related to the surface energy of solids. Usually the overwhelming part is the work of plastic deformation. Therefore, having the values of the friction force and the coefficient of friction, as well as data on mechanics and kinematics in the contact interaction of solids, it is possible to solve a number of problems in thermal physics, thermodynamics, cutting theory, metal working by pressure, etc. The contact interaction of an abrasive particle and a metal surface is based on the ratio of their strengths: if abrasive particles have superiority in strength ratio, then microcutting or plastic deformation of the metal occurs; if the metal turns out to be stronger and harder, then the abrasive is destroyed. Consequently, the intensity of wear during friction is determined by the ratio of the strength characteristics of the metal and the abrasive, since the strength and hardness of abrasive particles determine their ability to penetrate into the metal and destroy it during relative sliding by microcutting and plastic crushing.

Irreversible plastic deformations in the near-surface layer occur if specific loads in the form of stress intensity σ_i exceed the yield point σ_T metal. This process can intensify if intense heating occurs in the contact zone, which can cause structural and phase transformations in the metal surface. Plastic deformation leads to a significant change in the physic - mechanical and chemical properties of metals [12-14]. In a deformable surface layer of a metal, with an increase in the degree of deformation, all indicators of resistance to deformation increase: the limits of elasticity, yield and strength, and the hardness of the metal also increases. Simultaneously with this phenomenon, there is a decrease in plasticity indicators (relative elongation, relative contraction, impact strength); thermal conductivity, corrosion resistance decrease, electrical resistance increases, magnetic properties of ferromagnetic metals change, etc. The change in the mechanical properties of metals, in particular, an increase in their strength characteristics, is largely explained by the increasing resistance to displacement of dislocations - linear imperfections of the crystal structure of metals - with deformation. The main areas of increased resistance to displacement of dislocations are areas of intersection of slip planes. Different orientations of slip planes in polycrystal grains and, accordingly, different values of elastic deformation in individual grains in the initial stage of plastic deformation, lead to the formation of residual stresses of the second kind during unloading. These stresses form forces that are balanced between the individual grains of the polycrystal.

Thus, based on the above material, it can be stated that in order to solve a specific technological problem in abrasive blasting, it is necessary to consider a complex of interrelated positions and concepts that characterize the entire set of physical and mechanical phenomena in the process of contact interaction of an abrasive particle and a metal surface. Considering the importance of schematization of contact interaction for abrasive blasting, it is necessary to use some regularities of the shot-percussion process [15-18] and a number of assumptions typical for grinding when microcutting with a single abrasive grain is considered.

Experimental studies of the process of abrasive blasting of linter saw teeth were carried out on a sandblasting apparatus installed and operated in the mechanical workshop of GAUCH LLC (NPO Technolog). Conditions and regimes of treatment are as follows: air pressure p=0,1…0,4 MPa (1MPa=10 kgp/cm^2=10 atm); attack angle α=15…60^0, abrasive particle - black silicon carbide SC graininess 40. Saw blade material - U8G carbon tool steel (temporary tensile strength σ_V=1150 Н/мм^2; relative extension δ= 6%; hardness HRA 67-70).

Discussions.

Linter saws after abrasive blasting of the teeth resulting in a favorable micro-profile [19, 20] surface of teeth (height of unevenness H=2,04…3,75 μm at pressure p=4 atm and the step of irregularities along the tops of more than 20 μm) and strain hardening (degree of work-hardening U=12,9...24,2%, depth of work-hardening h_H=0,162 mm) of their thin surface layer due to microcutting and impact of abrasive particles, were installed on a 5LP linter in the genie - linter shop of the Piskent cotton plant of Tashkent region.

Production tests of linter saws were carried out on cotton seeds obtained after ginning cotton - hand-picked raw cotton, grade 1/2, selection S-6524 with a moisture content of 9%. The service life of linter saws, which underwent teeth processing in a stream of abrasive particles of black silicon carbide, was more than 96 hours, which is 2 times more than the service life of factory saws without processing. Analysis of the average values (from three samples) of the quality of seeds and linters showed (table) significant advantages of linter saws with pre-treated teeth with a flow of abrasive particles, which contribute to the activation of the tank surfaces of the teeth due to the formation of a favorable microprofile. At the same time, the mechanical damage to the seeds was 0,9%, which is 25% less compared to linting with factory saws. Seed hairiness is 5,5%, which is 20% less than a similar indicator with linting factory saws without teeth processing.

table 1

Results of comparative laboratory studies of seed quality

№ p.p.	Name of seed indicators	Research data	
		Experimental saws	Factory saws
1.	Mechanical damage, %	0,9	1,2
2.	Debris,%	0,2	0,2
3.	Humidity,%	7,8	7,8
4.	Pubescence,%	5,5	6,8

For comparison, Fig. 3 shows seeds after linting on machines started simultaneously after 24 hours of operation.

a) *b)*

Figure.3. Visual assessment of comparative experimental studies of the linting process

a – linting with factory saw blades;

b - linting with saw blades after abrasive blasting of teeth

Conclusion.

Thus, a high efficiency and technological rationale for the use of abrasive blasting of the lateral surfaces of linter saw teeth has been achieved, which creates a work hardening of the surface layer and a rational surface micro-profile for their activation. Analysis of the aggregates of physical and mechanical phenomena during abrasive blasting allows us to identify some patterns and get as close as possible to the essence of the formation of the quality of the surface layer, characterized by a number of geometric and mechanical parameters.

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