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Surface plastic deformation method for increasing the wear resistance of fire grates in fiber separating machines

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Abstract. The article covers materials on the influence of the wear resistance of cast iron grates of fiber separating machines on the technological clearance between them in the mentioned above grate. It has been shown that the main criterion for the performance of grate bars is their wear resistance, and at the same time, the amount of grate wear should be limited by the required technological clearances in the working part of the grate. It has been revealed that the method of surface plastic deformation can be used to create hardening (strain hardening) of the surface layer in order to increase the wear resistance of cast iron grates. For this purpose, a substantiation for strengthening technology for grate bars in the form of shot-impact treatment with microballs with a diameter of 0.3-0.4 mm, directed at the strengthening surface at an angle of 900 at a compressed air pressure of 0.3-0.4 MPa has been made. Based on data from experimental studies of the wear resistance of grates under production conditions, the values of their one-sided wear for hardened gin and linter grates have been obtained, which indicate a significant reserve of performance compared to grates without treatment.

1 Introduction

1.1 Requirements for the fire grate

The grates (Figure 1) make up the fire grate in fiber separating machines (saw gins, linters) used in cotton processing, and are an important part of the working chamber. They are designed to pass saw blades through the clearances between them into the working chamber and freely remove from it the fiber torn from the seeds by the teeth of the saw blades.

The technological requirements for the grate provide for a deviation from flatness between individual grates in the working part equal to 0.6-0.8 mm, in the rest – 2 mm [1]. Seeds are not allowed to pass through the clearances between the grates along with fibers

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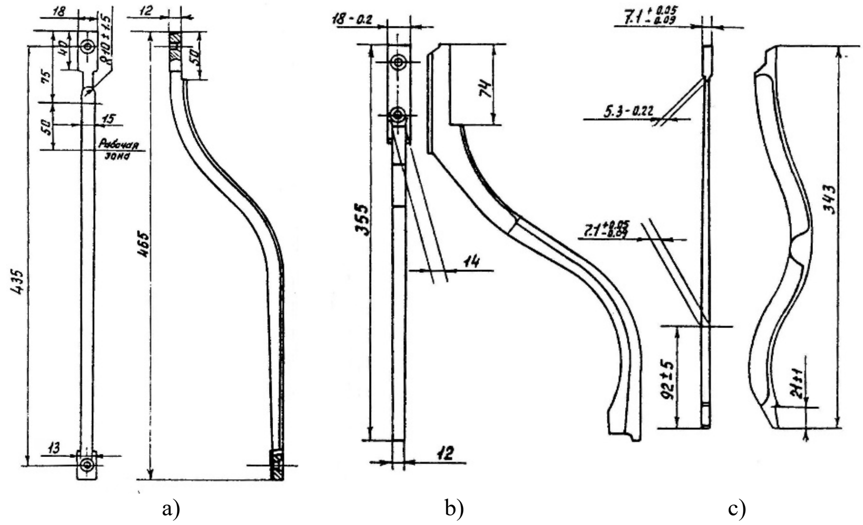
within the working area, which is 30 mm long (15 mm up and down) and within which the fiber is separated from the seed during ginning.

The number of grates in the fire grate is one more than the number of saws installed in the saw cylinder of the gin or linter. When assembling grates into a fire grate, technological clearances are provided for the passage of cylinder saw blades between them, which are 3±0.2 mm for gins and 2.8±0.3 mm for linters. Compliance with the inter-grate clearances is a necessary condition for the normal operation of the saw-grate system of fiber separating machines.

During the process of ginning and linting, a malfunction of the fire grate occurs such as wear of the grates in the working part and, as a result, the expansion of a given clearance (slot) in the places where saw teeth pass, which can contribute to the entry of whole seeds into waste and fibrous products. Therefore, grate bars must have high wear resistance, which is the main performance criterion for them.



a) b) c)

Fig. 1. Grates of the fiber separating machine: a- gin regular brand DP.AN.005; b- gin console brand 5DP.03.003; c- linter brand EH109-67B.

The grates are made by casting from gray cast iron grade SCh15 brand, which has a ferrite or ferrite-pearlite structure of the metal base with the following approximate composition [2]: 3.5-3.7% *C*; 2.0-2.6% *Si*; 0.5-0.8% *Mn*; ≤0.3% *P*; ≤0.15 *S*. Gray cast iron used as a structural material has the following mechanical properties: tensile strength σ_{ts}=115 MPa, hardness *HB* 113-129, relative elongation δ up to 0.5%. In calculation practice, when designing machine parts made of gray cast iron, approximate relationships between the tensile strength σ_{ts}, compression σ_{cs} and bending σ_{bs} can be used [3] $4\sigma_{ts}= 2\sigma_{bs}= \sigma_{cs}$

The manufacture of grates from gray cast iron SCh15 brand is justified by the fact that they experience low loads during operation and therefore castings with a wall thickness of 10-30 mm can be used. Mechanical processing of grate bars is carried out using special equipment and the roughness of the surface that comes into contact with the raw roller and seeds must be equal to *Ra* = 1.25-0.63 microns, and the side surfaces in the workplace be equal to *Ra = 0.63* microns.

For normal operation of the saw-grate system of fiber separating machines, it is necessary to observe the recommended value of the technological clearance in various sections of the fire grate (Table 1).

Table 1. The size of the technological clearance in the working part of the fire grate between two replaceable grates.

Fiber separating machine	Technological clearances, *S* mm			Surface roughness *Ra*, micron	
	in the working part	in the upper part	in the lower part	of the working part	of the side surface
Gin saw	3±0.2	$3.8^{+1.2}$	$3.8^{+1.2}$	1.25-0.32	0.63…0.32
Linter	2.5-3.0	3.0-3.5	3.5-4.75	2.5-0.63	1.25-0.63

1.2 Ensuring wear resistance of grates

During the process of fiber separation (ginning and linting), loss of the performance of fire grate occurs due to wear of individual grates, the surfaces of which enter the working area of the cotton processing machine. Wear, in this case mechanical (abrasive), of parts of the working parts of machines is carried out under specific conditions: contact of the working metal surfaces of the parts (side faces of cast iron grates, teeth of steel saw blades) with the fibrous mass of cotton occurs for a very short time at the rotation speed of the saw cylinder gin n=730 rpm; the fibrous mass of processed raw cotton with variable humidity and contamination contains solid impurities in the form of silicon dioxide (microhardness 10^4…$1.2\cdot10^4$ MPa), minerals of increased hardness (granite - $1.68\cdot10^4$ MPa; corundum - $2.29\cdot10^4$ MPa).

It should be noted that the hardness of the given abrasive particles significantly exceeds the hardness of structural materials (gray cast iron, carbon steel) for the manufacture of parts of the working body of fiber separation machines, which is an indispensable condition for micro-cutting when two solid bodies come into contact during abrasive processing. The intensification of wear is enhanced by the moisture content of the fibrous mass, which increases friction upon contact with the metal surface of the parts.

The wear resistance of the working part of the grate is increased by heat treatment, although according to A.P. Gulyaev, for ordinary gray cast iron, heat treatment is practically rarely used, since it is not particularly effective [4]. Despite the low ductility of gray cast irons (δ=0.2…0.5%), experimental studies of strain hardening under impact on samples of gray pearlitic cast iron SCh24 brand showed an excess of the initial microhardness of 2625 MPa by 71.4% after reaching 10 blows of the indenter (head of the impact driver made of hardened steel ShKh15 with microhardness 9000 MPa). Consequently, the possibility of implementing the method of preliminary hardening by surface-plastic deformation (SPD) creates a technological advantage, expressed in the fact that for hardening it is possible to do without heat treatment and without the expense of alloying elements.

Among the dynamic methods of SPD, the most effective with wide technological capabilities is hardening with microballs with shot diameter d=0.3...0.4 mm [5-6]. Compared to other methods of shot peening (shot blasting, pneumodynamic, etc.), hardening with microballs has a significant advantage in terms of the specific kinetic energy E_{sie} (kJ/(mm^2·min)), which is a general criterion for assessing shot peening modes. Thus, when hardening with microballs, E_{sie} = 74 kJ/(mm^2·min), which significantly exceeds the specific kinetic energy of the shot during pneumodynamic hardening, equal to 20 kJ/(mm^2·min).

If at a value of E_{sie} = 5.352 kJ/(mm^2·min) hardening of gray cast iron occurs, then when hardening with microballs with its level of specific kinetic energy, the manifestation of the effect of strain hardening is obvious.

2 Theoretical-experimental research method

Contact interaction during shot-impact hardening of machine parts is characterized by a free impact of the shot, accompanied by elastoplastic penetration of the metal layer into the surface, causing deformation of the contact zone. In the general case, a complex inhomogeneous stress-strain state arises, corresponding to a local deformation zone with a changing boundary.

The process of collision of a non-deformable spherical indenter with a softer metal surface can be described by relations arising from the assumption that the average penetration resistance pressure or the average flow pressure (yield strength σ_T) on the contact surface is assumed to be constant:

$$P = 2\pi\sigma_T Rh = -m\frac{d^2h}{dt^2} \tag{1}$$

or, replacing *2R=D*, we present the equation of motion of a spherical indenter (ball) in the processed medium in the form

$$\frac{d^2h}{dt^2} + \frac{\pi D\sigma_y}{m}h = 0, \tag{2}$$

where *P* is the load on the ball when inserted into the plastic zone (impact force);
m, D are mass and diameter of the ball, respectively;
h is the depth of ball penetration.

The solution to differential equation (2) is written in the form

$$h = v_0\sqrt{\frac{m}{\pi D\sigma_y}}sin(\sqrt{\frac{\pi D\sigma_y}{m}}t)\text{ , mm} \tag{3}$$

where v_0 is the initial impact speed, m/s;
t is impact duration (impact time), s.

From expression (3) we can determine the maximum penetration (compression) of the spherical indenter

$$h = V_0\sqrt{\frac{m}{\pi D\sigma_y}}, \tag{4}$$

provided that

$$sin\sqrt{\frac{\pi D\sigma_y}{m}}t = 1; \sqrt{\frac{\pi D\sigma_y}{m}}t = \frac{\pi}{2}$$

whence the time corresponding to the duration of contact upon impact will be:

$$t = \frac{\pi}{2}\sqrt{\frac{m}{\pi D\sigma_y}} \tag{5}$$

Thus, using relations (4) and (1), it is possible to calculate the impact force *P*, which affects the important parameter of strain hardening - the hardening depth h_H and determined by the formula of S.G. Heifetz

$$h_H = \sqrt{P/(2\sigma_y)}\text{, mm} \tag{6}$$

Experimental studies on shot-impact processing of the side surfaces of the working sections of grates with microballs were carried out using a conventional sandblasting machine. In the experiments, cast steel shots (CSS) were used from low-carbon steel in accordance with GOST 11964-81E, hardened at a temperature of 860-890°C with low-temperature tempering at 180-220°C for 1.5-2 hours. The shot has a hardness of *HV* 365-545, strength when tested under static load compression – not less than 6000 *N*.

Mode and conditions of shot-impact processing with microballs: compressed air pressure *p*=3-4 atm (0.3-0.4 MPa), microball diameter *d*=0.3-0.4 mm, angle of attack α=90°. distance from the nozzle of the abrasive blasting gun to the surface to be hardened *l*=15-20 cm.

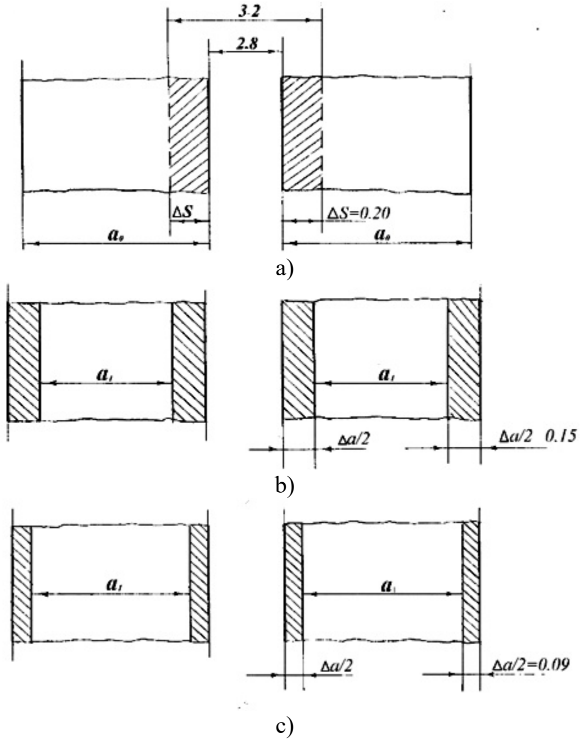
Cast iron grates were tested under production conditions after strengthening their side surfaces in the working part with microballs. In accordance with the methodology and plan of the experiments, grates with and without surface treatment in a set of 5 pieces were installed on one 7DP gin, which created the same operating conditions.

3 Results of research, their discussion and analysis

For testing, raw cotton was used from the harvest of 2022, selection “Sulton”, “Namangan-77”, grade 1, 2 and 3, hand-picked, weediness from 3 to 12-14%, humidity from 6-7 to 20-22%. As evidenced by the data of experiments conducted on gin in the conditions of a cotton gin plant, grates strengthened by shot-impact treatment with microballs had linear wear Δa 1,7 times less than grates without treatment with an average value of Δa=0.176 mm over a period of time t=105 working days. Wear of grate bars without preliminary dynamic treatment over the same period of time was Δa=0.304 mm.

The wear of the hardened linter grates during the same test period averaged Δa=0.14 mm, and that of the non-strengthened ones Δa=0.31 mm, i.e. wear resistance is 2.2 times greater.

Based on the value of the technological clearance S (Table 1), defined as the difference between the limit values of 3±0.2 mm and the component ΔS=0.4 mm, it is proposed to limit the wear value Δa of the grate bars to the value ΔS, i.e. $\Delta a \leq \Delta S$. Figure 2 shows a comparison of the so-called tolerance field for the technological clearance and the amount of wear of the grates (one-sided).



a)

b)

c)

Fig. 2. Comparison of grate wear results with technological clearance between them: a) after tolerance ΔS for the technological clearance; b) wear of grates of the gin $\Delta a=a_0-a_1$ without treatment of working surfaces during the control test time; c) wear of hardened grates of the gin $\Delta a=a_0-a_1$ during the control test time.

Taking into account the data from experimental studies of the wear resistance of gin grates, the following was obtained: the values of one-sided wear $\Delta a/2$=0.09 and 0.15 mm respectively to reinforced grates and without treatment with a clearance tolerance of $\Delta S/2$ = 0.2 mm. As can be seen from a comparison of the given wear data, for hardened grates there is still a significant reserve of operability. To evaluate it numerically and make a predictive assessment, it is necessary to create an equation for the development of wear, which, with a variable wear rate, is approximated by a parabola of the form:

$$\overline{x(z)} = a + bz + cz^2, \tag{7}$$

where the parameters a, b and c can be determined from the equation obtained by the least squares method

$$am + b\sum z_i + c\sum z_i^2 = \sum x_i, \tag{8}$$

In equation (8) m is the number of observations; - varies from i=1 to m. In a particular case, it is possible to approximate a parabola of the form

$$\overline{x(z)} = cz^2, \tag{9}$$

where parameters $a=0,\ c=0.$

Using data from a study of the wear resistance of grates for gins using equation (9), an equation for the development of wear was obtained

$$t=3389.7\Delta a^2 \tag{10}$$

where $x(z)=t;\ z=\Delta a.$

Similarly, the wear development equation for cast iron grates without preliminary hardening was obtained:

$$t = 1136.2\Delta a^2; \tag{11}$$

Using the obtained wear development equations (10) and (11), under the conditions of this experiment, it is possible to determine the durability of the grates during ginning, taking into account preliminary hardening by treatment with microballs and without treatment, which, respectively, amounted to 542 and 182 days when the maximum wear of the grate bars was reached, equivalent to the maximum tolerance for technological clearance between the gin grates is 0.4 mm.

4 Conclusion

Therefore, based on preliminary dynamic treatment of the working surfaces of cast iron grates of gins and linters with microballs, a significant increase in their performance due to hardening of their surface layer has been achieved. The resulting effect of strain hardening allows maintaining the regulated technological clearance between the grates for a long time due to their increased wear resistance. It has been proposed to consider the absolute value of the linear wear of the grates with the introduced concept of tolerance for the technological clearance between the grates, which is essential criterion of the wear.

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