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The influence of the alloying of the auger by the chromium on its wear during dehydration process of municipal solid waste in the garbage truck

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Abstract

The article is dedicated to the study of the influence of the alloying of the auger by the chromium on its wear during dehydration of solid waste in the garbage truck. Using the method of regression analysis, the hyperbolical dependencies of auger wear depending on the chromium content in its hardened steel for different values of the friction path are determined. Graphical dependences of augur wear depending on the chromium content in its hardened material as a function of the friction path are made up, and it confirms sufficient convergence of the obtained dependencies. Carried out additional regression analysis allowed to determine that that during two weeks of operation of the auger during dehydration of solid waste in the garbage truck increasing of the chromium content in its hardened material from 0.25% to 12% reducing the speed of the wearing and energy consumption of solid waste dehydration from 12.2% to 3.1%, and, consequently, to reduce the cost of the process of their dehydration in the garbage truck. It is shown the graphical dependence of the reduction of energy consumption of dehydration of solid household waste by the hardened auger due to its alloying by the chromium. It was established the expediency of further research to determine the rational content and structural state of the material of the auger and the ways to increase its wear resistance.

Key words: wear, chromium content, auger press, garbage truck, dehydration, solid waste, regression analysis

Introduction

The increasing of the wear resistance and reliability of machine parts is the important task of the municipal machine building [1, 2]. A promising technology for primary processing of municipal solid waste (MSW), aimed at reducing both the cost of transportation of solid waste and the negative impact on the environment is their dehydration, accompanied by pre-compaction and partial grinding. Dehydration of solid waste in the garbage truck is performed using a conical screw, the surface of which due to the existing friction wears out intensively. This is due to the fact that solid waste contains small metal parts, glass, ceramics, stones, bones, polymeric materials, which have abrasive properties. Besides, the presence of moisture 39-92% by weight in MSW creates an aggressive corrosive environment. For the manufacturing of the augers, the alloyed steels are widely used. The usage of steels and cast irons which are alloyed by chromium is well-grounded. Such alloys harden well and have high resistance to corrosion and abrasive wear. Therefore, the study of the influence of the chromium content in the hardened steel of the auger on its wear during dehydration of solid household waste in the garbage truck is a topical task.

Literature review

The results of experimental studies of wear resistance of different auger materials with different thermal and chemical-thermal treatment in a corrosive-abrasive environment on special friction machines that simulated the operating conditions of extruders in the processing of feed grain with saponite mineral impurities are published in the paper [3]. The authors found that the wear resistance of materials in a corrosive-abrasive environment at elevated temperatures depends not only on the hardness of the friction surface, but also on its structure and phase composition and changes in the hardness gradient along the depth of the hardened layer. To ensure high wear resistance of extruders in the manufacture of animal compound feed with impurities of the mineral saponite, it is recommended to use for the manufacture of parts of the extrusion unit steel X12, hardened by nitro-hardening technology.

The paper [1] is dedicated to the research of the tribotechnical characteristics of cast high-chromium alloys followed by heat treatment.

The author of the article [4] investigated the influence of chromium alloying of structural steel on its abrasive wear resistance after high-temperature thermomechanical treatment. It is noted that the combined treatment, which consists of a combination of chromium alloying in the amount of 1 ... 5% and high-temperature thermomechanical treatment can be recommended for practical use as an effective means of increasing the strength of steels. The hardening of steel in this structural state reaches its maximum value after alloying by 1 ... 2% of chromium.

In the article [5], a mathematical model for calculating the wear rate of triboelements in a tribosystem operating in conditions of corrosion and abrasive wear was developed. The input factors were: active acidity, abrasiveness, roughness, load and sliding speed. Theoretically, the degree of influence of the above factors on the wear rate is established. It was found that abrasiveness is the most important factor, followed by the degree of decline – the level of active acidity and load.

Authors of the article [6] presented a new design of the auger with a sectional elastic surface, which is designed to reduce the degree of damage to the grain material during its transportation. The theoretical calculation of the interaction of the grain with the elastic section of the auger is carried out. A dynamic model has been developed to determine the influence of structural, kinematic and technological parameters of the elastic auger on the time and path of free movement of bulk material particles during their movement between sections, as well as to exclude the possibility of grain material interaction with the non-working surface of the auger working body to reduce the possibility of its damage.

In the paper [7] it was determined that restoration of the auger requires surfacing or spraying a layer of a certain thickness on the end part of the coil of the auger, while the width of the restored layer is usually a few millimeters. An algorithm for selecting the optimal composite powder material for plasma spraying in order to increase the wear resistance of the working surfaces of machine parts, in particular the auger, is described. Plasma spraying of composite powder materials, according to the authors, will increase the durability of the auger by 2-3 times, which will reduce repair costs by tens of times.

The influence of geometrical parameters on productivity and design of the briquetting machine using the model of pressure based on the theory of piston flow is investigated in the article [8]. An analytical model that uses a pressure model was also developed based on Archard wear law to study the wear of augers of biomass briquetting machines. The developed model satisfactorily predicted the wear of the auger and showed that the greatest influence on it have the speed of rotation and the choice of material. The amount of wear increases exponentially to the end of the auger, where the pressure is the highest. Changing the design of the auger to select the optimal geometry and speed with the appropriate choice of material can increase the life of the auger and the productivity of the machine for briquetting biomass.

The analysis of the process of screw briquetting of plant materials into fuel and feed is investigated in the work [9]. Regularities of this process are the basis for determining the rational parameters of the working bodies. When designing briquette presses it is necessary to consider deformation of biomass taking into account change of physical and rheological properties at the moment of interaction with the working surfaces of the auger.

In the article [10] the wear of a twin-auger extruder of rigid PVC resins is investigated. The pressures around the cylinder when extruding two rigid PVC resins in a laboratory extruder with a diameter of 55 mm were measured and the forces acting on the auger core were determined. Numerical simulation of the flow was performed using the power parameters of the viscosity of the resins.

The process of pressing wood chips in auger machines was investigated in the work [11]. The processes occurring in different parts of the auger are established, formulas are defined that allow to calculate the loads acting on the auger coils, as well as to determine the power required for pressing. The specific energy consumption and the degree of heating of raw materials during pressing are determined.

The results of experimental studies of the process of solid dehydration based on the planning of the experiment by the Box-Wilson method are shown in the article [12]. Quadratic regression equations with the 1st order interaction effects were obtained using rotatable central composite planning for such objective functions as humidity and density of pre-compacted and dehydrated MSW, maximum drive motor power, energy consumption of solid waste dehydration. This allowed to determine the optimal parameters of equipment for dehydration by the criterion of minimizing the energy consumption of the process (auger speed, the ratio of the radial gap between the auger and the body, and the ratio of the auger core diameter to the outer diameter of the auger on the last coil) for both mixed and “wet”.

In the article [13] the improved mathematical model of work of the dehydration drive of MSW in the garbage truck is suggested that takes into account wear of the auger, which allowed to research numerically the dynamics of this drive during the start-up, and to define that with the increase of wear of the auger pressure of working liquid on the speed of the auger it is significantly reduced. The power regularities of change of the nominal values of pressures at the inlet of the hydraulic motor, angular speed and frequency of rotation of the auger from values of its wear are defined, the last of which describes detuning from optimum frequency of rotation of the auger in the course of its wear. It is established that the wear of the auger by 1000 μm leads to an increase in the energy consumption of solid dehydration by 11.6%, and, consequently, to an increase in the cost of the process of their dehydration in the garbage truck and accelerate the wear process.

In the paper [14], the influence of carbon content in the auger material on its wear during dehydration of solid waste in the garbage truck was investigated by means of the regression analysis method. It was also found that during operation and the wearing process of the auger on the path s = 56850 m during dehydration of solid waste in the garbage truck, the increase of the carbon content in the auger material from 0.2% to 2.1% leads to a decrease in the growth rate of energy consumption of solid waste dehydration from 19.6% to 4.4%, and, consequently, to reduce the cost of dehydration in the garbage truck.

Purpose

Researching the influence of the chromium content in the hardened steel of auger on its wear during dehydration of solid waste in a garbage truck.

Methods

Determination of paired dependencies of auger wear from the chromium content in the hardened steel was performed by regression analysis [15]. Regressions were determined on the basis of literalizing transformations, which allow to reduce the nonlinear dependence to the linear one. The coefficients of regression equations were determined by the method of least squares using the developed computer program "RegAnaliz", which is protected by a copyright registration certificate, and is described in the article.

The following dependencies were used to determine the energy consumption of solid dehydration taking into account the auger wear [13]:

$$\begin{aligned} E &= 1504 - 15.92w_0 + 0.3214\rho_0 - 1.069n(u) - 2061(\Delta_{aug} + u)/(D_{\min} - 2u) - 1947(d_{\min} - \\ &-2u)/(D_{\min} - 2u) + 9.118\cdot10^{-4} w_0\rho_0 + 0.002142 w_0 n(u) + 18.12 w_0(\Delta_{aug} + u)/(D_{\min} - 2u) - \\ &-2.115 w_0(d_{\min} - 2u)/(D_{\min} - 2u) + 4.392\cdot10^{-4}\rho_0 n(u) - 2.005\rho_0(\Delta_{aug} + u)/(D_{\min} - 2u) + \\ &+0.3361\rho_0(d_{\min} - 2u)/(D_{\min} - 2u) + 0.09031 w_0^2 - 7.923\cdot10^{-4}\rho_0^2 + 0.008241 n(u)^2 + \\ &+104172[(\Delta_{aug} + u)/(D_{\min} - 2u)]^2 + 1318[(d_{\min} - 2u)/(D_{\min} - 2u)]^2 \ [\text{kWh/tons}]; \end{aligned} \quad (1)$$

$$n = 52.43 - 1.276\cdot10^{-3} u^{1,5} \ [\text{rpm}], \quad (2)$$

where E – is the energy consumption of solid waste dehydration, kW·h/tons; ρ_0 – initial density of solid waste, kg/m^3; w_0 – initial relative humidity of solid waste, %; n – the nominal speed of the auger, rpm; u - auger wear, m; Δ_{aug} - radial clearance between auger and housing, m; d_{min} – outer diameter of the auger on the last coil, m; D_{min} is the diameter of the auger core on the last coil, m.

Results

The values of auger wear for different values of chromium content in the hardened steel of auger and friction path are given in Table 1 [3]. As a result of regression analysis of the data in Table 1, it was determined the hyperbolical dependencies of wear of the auger depending on the hardness of its surface for different values of the friction path:

$$u_{s=3000} = \frac{C_{Cr}}{0.02586C_{Cr} - 0.002768}; \quad (3)$$

$$u_{s=6000} = \frac{C_{Cr}}{0.01402C_{Cr} - 0.001645}; \quad (4)$$

$$u_{s=9000} = \frac{C_{Cr}}{0.009613C_{Cr} - 0.001109}; \quad (5)$$

$$u_{s=12000} = \frac{C_{Cr}}{0.007314C_{Cr} - 0.0008353}, \quad (6)$$

where u – wear, μm; C_{Cr} – chromium content in the hardened steel of auger, %; s – friction path, m.

Table 1

The results of regression analysis of the dependence of the wear of the auger depending on the chromium content in the hardened steel and the friction path [3]

№	Material of the auger	Chromium content in the auger material, %	Wear, μm, for the friction path, m			
			3000	6000	9000	12000
1	Steel 45	0.25	53	103	153	203
2	Steel ШХ15	1.5	43	80	116	152
3	Steel X12	12	39	72	105	138

Fig. 1 shows graphical dependences of auger wear depending on the chromium content in the hardened steel for different values of the friction path, made up using the dependences (3 - 6), which confirmed the sufficient convergence of the obtained dependencies compared with the data in the Table 1.

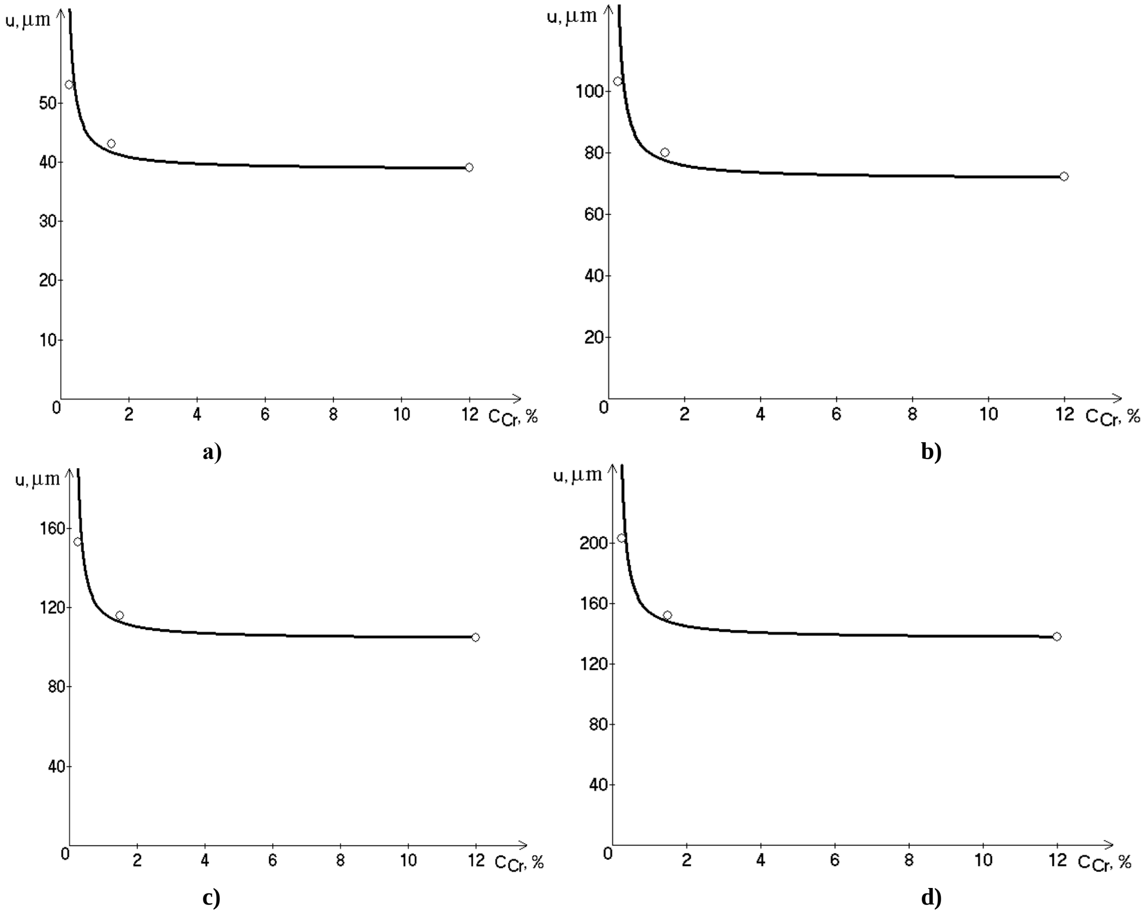


Fig.1 The wear of the auger depending on the chromium content in the hardened steel for different values of the friction path (a) – *s* = 3000 m, (b) – *s* = 6000 m, (c) – *s* = 9000 m, (d) – *s* = 12000 m: actual ○, theoretical —

Dependences (3 - 6) for different values of the friction path can be written in general as follows

$$u = \frac{C_{Cr}}{B(s)C_{Cr} - A(s)}, \qquad (7)$$

where $A(s)$, $B(s)$ – regression coefficients that depend on the path of friction.

After the additional regression analysis, the regression coefficients which depend on the friction path can be described by power laws:

$$A(s) = \frac{1}{66.64 + 0.09338s}; \qquad (8)$$

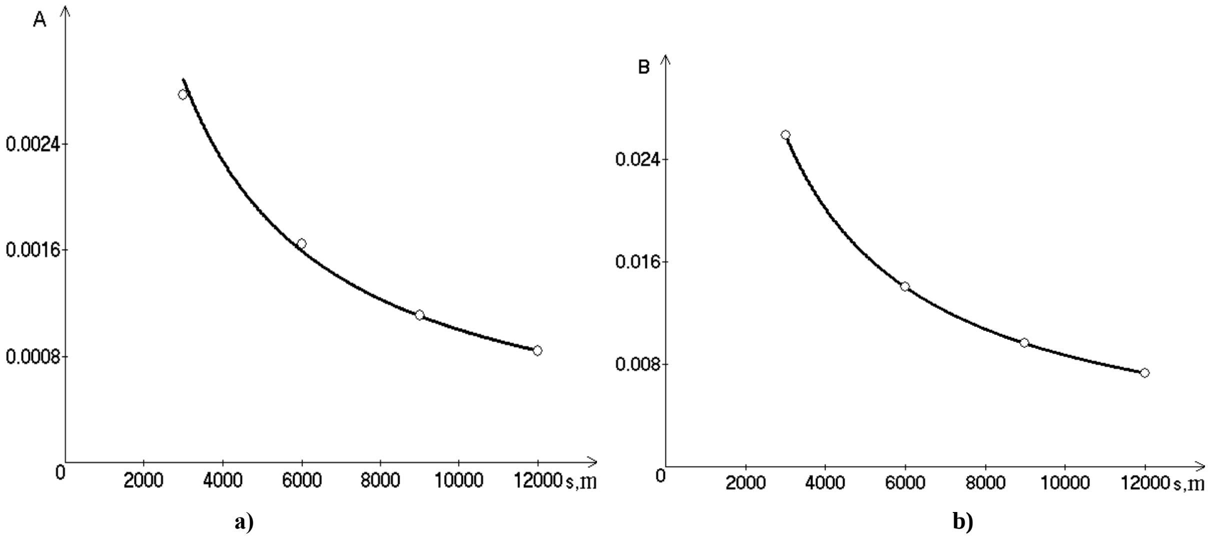
$$B(s) = \frac{1}{5.971 + 0.0109s}. \quad (9)$$

The results of the regression analysis are shown in Table 2, where the cells with the maximum values of the correlation coefficient R for each of the paired regressions are marked in gray. Figure 2 shows the graphical dependences of the regression coefficients on the path of friction, constructed using the dependences (8,9), which confirm the sufficient convergence of the obtained dependencies.

Table 2

The results of regression analysis of the dependence of the wear of the auger depending on the chromium content in the hardened steel for different values of the friction path

№	Type of regression	Correlation coefficient R for paired regressions					
		$u_{s=3000}=f(C_{Cr})$	$u_{s=6000}=f(C_{Cr})$	$u_{s=9000}=f(C_{Cr})$	$u_{s=12000}=f(C_{Cr})$	$A=f(s)$	$B=f(s)$
1	$y = a + bx$	0.78434	0.76548	0.74538	0.73568	0.95672	0.93902
2	$y = 1 / (a + bx)$	0.82777	0.81508	0.79543	0.78565	0.99911	1.00000
3	$y = a + b / x$	0.98985	0.99365	0.99664	0.99772	0.99597	0.99957
4	$y = x / (a + bx)$	0.99998	0.99998	0.99998	0.99999	0.98313	0.98541
5	$y = ab^x$	0.80603	0.79008	0.77000	0.76015	0.99128	0.98339
6	$y = ae^{bx}$	0.80603	0.79008	0.77000	0.76015	0.99128	0.98339
7	$y = a \cdot 10^{bx}$	0.80603	0.79008	0.77000	0.76015	0.99128	0.98339
8	$y = 1 / (a + be^{-x})$	0.99736	0.99873	0.99985	0.99998	0.98832	0.98832
9	$y = ax^b$	0.96900	0.96212	0.95287	0.94812	0.99742	0.99985
10	$y = a + b \cdot \lg x$	0.95954	0.95070	0.94075	0.93575	0.99540	0.98841
11	$y = a + b \cdot \ln x$	0.95954	0.95070	0.94075	0.93575	0.99540	0.98841
12	$y = a / (b + x)$	0.82777	0.81508	0.79543	0.78565	0.99910	0.99999
13	$y = ax / (b + x)$	0.97675	0.98128	0.98712	0.98955	0.91241	0.92863
14	$y = ae^{b/x}$	0.98414	0.98849	0.99284	0.99455	0.96816	0.98033
15	$y = a \cdot 10^{b/x}$	0.98414	0.98849	0.99284	0.99455	0.96816	0.98033
16	$y = a + bx^n$	0.72971	0.70897	0.68701	0.67645	0.89126	0.86559



a) b)

Fig. 2. Dependences of regression coefficients on the friction path (a) – $A = f(s)$, (b) – $B = f(s)$: actual○, theoretical —

After substituting the laws (8, 9) into the dependence (7), we obtain the law of wear of the auger depending on the chromium content in the hardened steel and the friction path

$$u = \frac{C_{Cr}}{C_{Cr} / (5.971 + 0.0109s) - 1/(66.64 + 0.09338s)}. \quad (10)$$

Fig. 3 shows a graphical dependence of the wear of the auger in the plane of the parameters of influence: the chromium content in the hardened steel and the friction path.

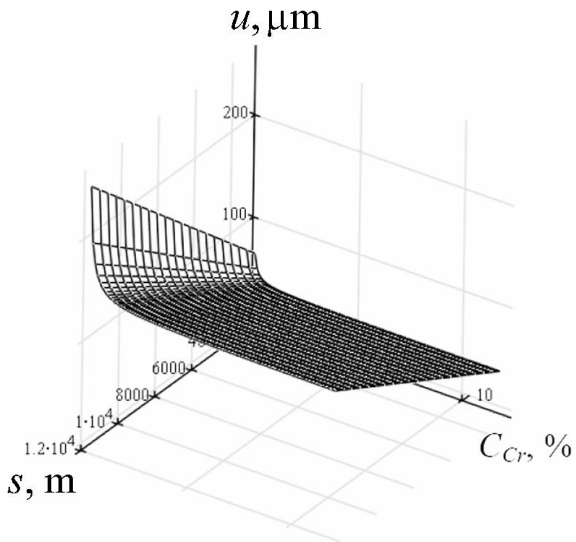


Fig. 3. The dependence of the wear of the auger *u* in the plane of the parameters of influence: the content of the chromium C_{Cr} in the hardened steel and the friction path *s*

Figure 4 shows the graphical dependence of the influence of the chromium content in the hardened steel of the auger of the device for dehydration of solid waste on the energy consumption of the process (*s* = 56850 m [14]), made up using dependencies (1, 2, 10).

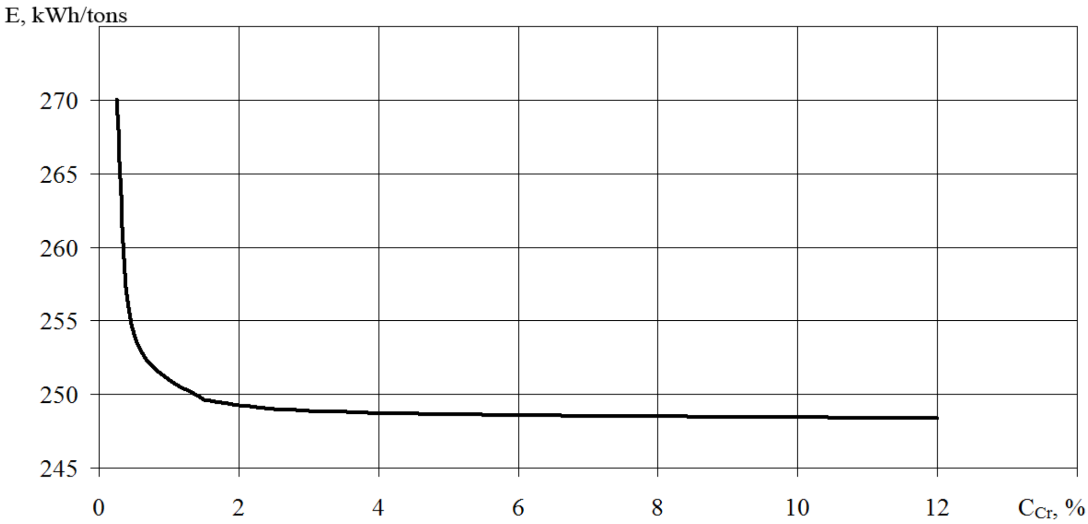


Fig. 4. The influence of increasing of the chromium content in the hardened steel of the auger on energy consumption of the MSW dehydration process after its operation and wear on the path s = 56850 m

As shown on the Fig. 4, after operation and wear on the path s = 56850 m during dehydration of MSW in the garbage truck, the increase in chromium content in the hardened steel of the auger from 0.25% to 12% leads to reduced energy consumption and to cheap the process of dehydration of solid waste in the garbage truck, which indicates the importance of determining the rational composition and structural state of the material of the friction surfaces of the auger and the ways to increase its wear resistance.

Conclusions

The hyperbolic dependencies of the auger wear depending on the chromium content in its hardened steel for different values of the friction path are determined. Carrying out additional regression analysis allowed to obtain the dependence of wear of the auger depending on the chromium content in its hardened steel and the friction path. It is established that on the way of auger wear s = 56850 m during dehydration of solid household waste in garbage truck, the increase of chromium content in auger steel from 0.25% to 12% allows to reduce energy consumption of solid waste dehydration from 12.2% to 3.1%, and, consequently, to reduce the cost of the process of dehydration in the garbage truck. Therefore, determining the rational composition and the structural state of the material of the friction surfaces of the auger and the ways to increase its wear resistance require further research.

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Березюк О.В., Савуляк В.І., Харжевський В.О. Вплив легування хромом шнека на його знос під час зневоднення у сміттєвозі твердих побутових відходів

Стаття присвячена дослідженню впливу легування хромом шнека на його знос під час зневоднення твердих побутових відходів у сміттєвозі. За допомогою використання методу регресійного аналізу визначено гіперболічні закономірності зносу шнека залежно від вмісту хрому в його гартованій сталі для різних значень шляху тертя. Побудовано графічні залежності зносу шнека залежно від вмісту хрому в його гартованому матеріалі як функції шляху тертя, підтверджено достатню збіжність отриманих закономірностей. Додатковий регресійний аналіз дозволив встановити, що при двотижневій експлуатації шнека для зневоднення твердих побутових відходів у сміттєвозі збільшення вмісту хрому в гартованому матеріалі шнека з 0,25% до 12% дозволяє знизити швидкість зношування та енергоємність зневоднення твердих побутових відходів з 12,2% до 3,1%, а, отже, і до здешевлення процесу їхнього зневоднення у сміттєвозі. Показана графічна залежність зниження енергоємності зневоднення гартованим шнеком твердих побутових відходів внаслідок його легування хромом. Виявлено доцільність проведення подальших досліджень з визначення раціонального складу і структурного стану матеріалу шнека та шляхів підвищення його зносостійкості.

Ключові слова: знос, вміст хрому, гартування, шнековий прес, сміттєвоз, зневоднення, тверді побутові відходи, регресійний аналіз