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Dependence of the wear rate on the microhardness of the coating of the auger hehydration in a garbage truck for municipal solid waste

O.V. Bereziuk[1], V.I. Savulyak [1], V.O. Kharzhevskyi [2], I.V. Vishtak[1]

[1]Vinnytsia National Technical University, Ukraine
[2]Khmelnytskyi national University, Ukraine
E-mail: berezyukoleg@i.ua

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Abstract

The article is dedicated to the study of the influence of the microhardness of the auger coating on its wear resistance during the dehydration of municipal solid waste in a garbage truck. The use of mathematical tools and appropriate regression analysis software allowed to determine the dependence between the auger wear rate and the microhardness of the coating. A graphical representation of the change in auger wear rate based on the microhardness of the coating was made up, confirming a significant convergence with the obtained dependence. The graphs illustrating the impact of the microhardness of the screw coating on its wear rate demonstrate the feasibility of increasing it. It was found that after operating and wearing out over a distance of s = 56850 m during the dehydrating of solid municipal waste in a garbage truck, increasing the microhardness of the coating from 2.7 GPa to 33.2 GPa leads to a decrease in energy consumption by 19 kWh/tons or 12% and reduces the cost of the dehydrating process. The feasibility of conducting additional research to determine further ways to increase the wear resistance of the auger was established.

Key words: wear, wear resistance, wear rates, coating microhardness, auger press, garbage truck, dehydration, municipal solid waste, regression analysis.

Introduction

One of the important tasks of municipal engineering is to improve the wear resistance and reliability of the executive components of machines [1, 2]. One of the promising technologies for primary processing of municipal solid waste (MSW), aimed at reducing the costs of MSW transportation and its negative impact on the environment, is their dehydration during the loading process into garbage trucks, accompanied by associated processes of pre-compaction and partial shredding. The dehydration of MSW in the garbage truck is performed by a tapered auger, the surfaces of which undergo intensive wear due to the presence of waste components with abrasive properties, such as small metal objects, glass, stones, ceramics, polymer materials, and bones. The aggressive corrosive environment is formed by the moisture present in the MSW in the range of 39...92% by weight. Augers are typically made from iron-based alloys. The application of wear-resistant coatings to increase wear resistance [3, 4] is substantiated. Therefore, determining the dependence of wear rate on the microhardness of the coating on the dehydrating auger in the garbage truck for municipal solid waste is a current task.

Analysis of recent research and publications

The evaluation of the effectiveness of the application of nano-sized coatings on surfaces subject to abrasive and erosive wear during operation of compressor blades of gas turbine engines, augers of mechanical mills, etc. is carried out in the article [3]. Two types of nanostructured coatings were chosen for the study – multilayer nanocoatings based on titanium and zirconium nitrides (Ti/Zr) and composite chromium coating with diamond nanoparticles (Cr-UDD). According to the results of gravimetric measurements, it was established that the rate of wear of the Ti/Zr nanolayer coating is 2 and 3.3 times lower than that of monolayer Ti and Zr, respectively.

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The work [1] examines the peculiarities of the influence of prior laser treatment on the phase composition, structure, and properties of nitrogenized layers on steels. It is shown that the qualitative and quantitative changes in the nitrogenized layer are determined by the pre-formed structural and phase state. The main dependencies of the influence of contour-radiation schemes of laser strengthening on the tribological characteristics of coatings are established.

In the materials of the work [5], the physical justifications for a significant increase in the strength of nano-layered metal composite materials compared to the additive strength of components are given. From a unified perspective, the main technological methods of forming multilayer nanostructures in alloys are considered. It is experimentally shown that the use of nano-layered steel and copper composites allows for a significant increase in wire strength and approach the lower limit of the theoretical value for iron alloys.

The construction of a mathematical model for calculating the wear rate of tribological elements in a tribological systems under conditions of corrosion-abrasive wear is published in [6]. The input parameters included active acidity, abrasiveness, roughness, load, and sliding speed. The theoretical study established the degree of influence of these factors on the wear rate: abrasiveness being the most significant factor, followed by the level of active acidity and load, respectively, in decreasing order of impact.

To reduce the degree of damage to granular material during its transportation, a new design of an auger with a sectional elastic surface is proposed [7]. In order to determine the influence of structural, kinematic, and technological parameters of the elastic auger on the time and path of free movement of particulate material between sections, as well as to eliminate the possibility of interaction between the granular material and the non-working surface of the auger working element to reduce its damage, a dynamic model was developed. This model was used to perform a theoretical calculation of the interaction between the grain and the elastic section of the auger.

The work [8] is dedicated to determining the regularities of microstructure formation in Cr-Ni-Fe-C alloys during the surfacing with powder ribbons PL AN-101 and PL AN-111. The aim is to determine the optimal microstructural state, alloying level, and increase the durability of coatings under high-temperature wear conditions. Recommendations are provided regarding the application areas of wear-resistant coatings deposited with the mentioned powder ribbons. It is established that in order to prevent the formation of graphite in the structure of the surfacing and considering the possible local increase in carbon content up to 5.5%, the nickel concentration should not exceed 13...14%.

In the materials of article [9], the influence of geometric parameters on the productivity and design of a briquetting machine is investigated using a pressure model based on the theory of piston flow. An analytical model using the pressure model was also developed based on the Archard wear law to study the wear of biomass briquetting machine augers. This model satisfactorily predicted the wear of the auger and showed that the rotational speed and material selection have the greatest impact on wear. It was found that the wear volume exponentially increases towards the end of the auger, where the pressure is highest. It is determined that modifying the auger design to select optimal geometry and speed, along with the appropriate material selection, can increase the productivity of the biomass briquetting machine and extend the service life of the auger.

As a result of morphological investigations [10] of friction surfaces, it was determined that the improvement of tribological properties is associated with the formation of a discrete anti-friction coating on the steel surface during frictional interaction with developed polymer composite materials. The increase in microhardness of the steel surface at filler concentrations in polymer composite materials from 0 to 10% is explained by the formation of an anti-friction coating, which is most stable at a filler content of 10%. Further decrease in microhardness with increasing filler content from 10 to 30% is related to its abrasive action on the friction pair, which partially destroys the obtained stable anti-friction coating.

The wear of a twin-auger extruder for rigid PVC resins was studied in the materials of article [11] using numerical flow modeling with power-law viscosity functions of the resins. The pressures around the cylinder during the extrusion of two rigid PVC resins in a laboratory extruder with a diameter of 55 mm and the forces acting on the auger core were determined.

The work [12] investigated the peculiarities of wood chip pressing in auger machines, as well as the processes occurring at different sections of the auger. Formulas were derived that allow for the calculation of loads acting on the auger flights and the determination of pressing power. Specific energy consumption and the degree of heating of the raw material during pressing were determined.

Using Box-Wilson rotatable central composite design, experimental results of the dehydration process of MSW were obtained and published in the work [13]. Quadratic regression equations with first-order interaction effects were obtained for the following response variables: moisture content and density of pre-compacted and dehydrated MSW, maximum power of the drive motor, energy consumption of MSW dehydration. This allowed for determining the optimal equipment parameters for dehydration based on the criterion of minimizing energy consumption, including the auger rotation frequency, the ratio of radial clearance between the auger and the housing, and the ratio of the core diameter of the auger to the outer diameter of the auger on the last turn, for both mixed and "wet" MSW.

An improved mathematical model of the operation of the municipal solid waste dehydration drive in the garbage truck taking into account the wear of the auger is proposed [14], which made it possible to determine by means of a numerical study of the dynamics of this drive during start-up that as the wear of the auger increases, the pressure of the working fluid at the input of the hydraulic motor of the drive increases, and the angular velocity and the rotation frequency of the auger is significantly reduced with constant supply of the working fluid. Power-laws of changes in the nominal values of pressures at the hydraulic motor inlet, angular velocity and rotation frequency of the auger depending on the amount of its wear were determined, the last of which describes the deviation from the optimal rotation frequency of the auger during its wear and was used to determine the energy intensity of solid waste dehydration taking into account the wear of the auger. It was established that the wear of the auger by 1000 μm leads to an increase in the energy consumption of solid waste dehydration by 11.6%, and, therefore, to an increase in the cost of their dehydration in the garbage truck and an acceleration of the wear process.

In the materials of the work [15], logarithmic dependencies of auger wear are determined depending on the hardness of its surface for different values of the friction path. Conducting an additional regression analysis made it possible to obtain the regularity of auger wear depending on the hardness of its surface and friction path, by means of which it was established that during two-week operation and wear of the auger during the dehydration of solid municipal waste in the garbage truck, the hardness of the auger surface increased from 2.31 GPa to 10.05 GPa leads to a decrease in the rate of growth of the energy intensity of dehydration of solid municipal waste from 16.7% to 1.5%, and, therefore, to a decrease in the cost of the process of their dehydration in the garbage truck.

Aims of the article

Determining the dependence of the wear rate on the microhardness of the coating of the auger dehydration in a garbage truck for solid municipal waste.

Methods

Determining the paired regularity of the rate of wear from the microhardness of the coating of the dehydrating auger in the garbage truck of municipal solid waste was carried out by the method of regression analysis. Regression was determined on the basis of linearization transformations, which allow to reduce the non-linear dependence to a linear one. The coefficients of the regression equation were determined by the method of least squares using the developed computer program "RegAnalyz", which is protected by a certificate of copyright registration for the work.

To determine the energy intensity of solid waste dehydration, taking into account the wear of the auger, the following laws were used [14]:

$$\begin{aligned} E = {} & 1504 - 15,92 w_0 + 0,3214 \rho_0 - 1,069 n(u) - 2061(\Delta_{aug} + u)/(D_{\min} - 2u) - 1947(d_{\min} - \\ & - 2u)/(D_{\min} - 2u) + 9,118 \cdot 10^{-4} w_0 \rho_0 + 0,002142 w_0 n(u) + 18,12 w_0 (\Delta_{ш} + u)/(D_{\min} - 2u) - \\ & - 2,115 w_0 (d_{\min} - 2u)/(D_{\min} - 2u) + 4,392 \cdot 10^{-4} \rho_0 n(u) - 2,005 \rho_0 (\Delta_{aug} + u)/(D_{\min} - 2u) + \\ & + 0,3361 \rho_0 (d_{\min} - 2u)/(D_{\min} - 2u) + 0,09031 w_0^2 - 7,923 \cdot 10^{-4} \rho_0^2 + 0,008241 n(u)^2 + \\ & + 104172 [(\Delta_{aug} + u)/(D_{\min} - 2u)]^2 + 1318 [(d_{\min} - 2u)/(D_{\min} - 2u)]^2 \left[\mathrm{kW} \cdot h/\mathrm{tons}\right]; \end{aligned} \tag{1}$$

$$n = 52,43 - 1,276 \cdot 10^{-3} u^{1,5} \text{ [rpm]}, \tag{2}$$

where E is the energy intensity of solid waste dehydration, kWh/tons;
ρ_0 – initial municipal solid waste density, kg/m^3;
w_0 – initial relative humidity of solid waste, %;
n – nominal auger rotation frequency, rpm;
u – auger wear, m;
Δ_{aug} – radial clearance between the auger and the housing, m;
D_{min} is the outer diameter of the auger on the last turn, m;
d_{min} – the diameter of the auger core on the last turn, m.

Results

The values of the wear rate for coatings with different microhardness are given in the Table 1 [3].

As a result of the regression analysis of the data in the Table 1, the regularity of the change in the rate of wear of the auger depending on the microhardness of the coating is determined:

$$\gamma = \frac{1}{0,1158 + 0,2316 H} \text{ [mg/h]}, \tag{3}$$

where γ – wear rate, mg/h; H – coating microhardness, Gpa.

Table 1

Effect of coating microhardness on wear rate [3]

Coating	12X18H10T	Cr	Cr-UDD	ZrN	TiN	TiN/ZrN
Coating microhardness H, GPa	2,7	7,6	10,3	15,2	21,6	33,2
Wear rate γ, mg/hour	0,8941	0,7176	0,2824	0,4	0,2039	0,1216

In the Fig. 1 is shown the graphical dependence of the change in the rate of wear of the auger on the microhardness of the coating, constructed using dependence (3), which confirms the sufficient convergence of the obtained regularity compared to the data given in Table 1.

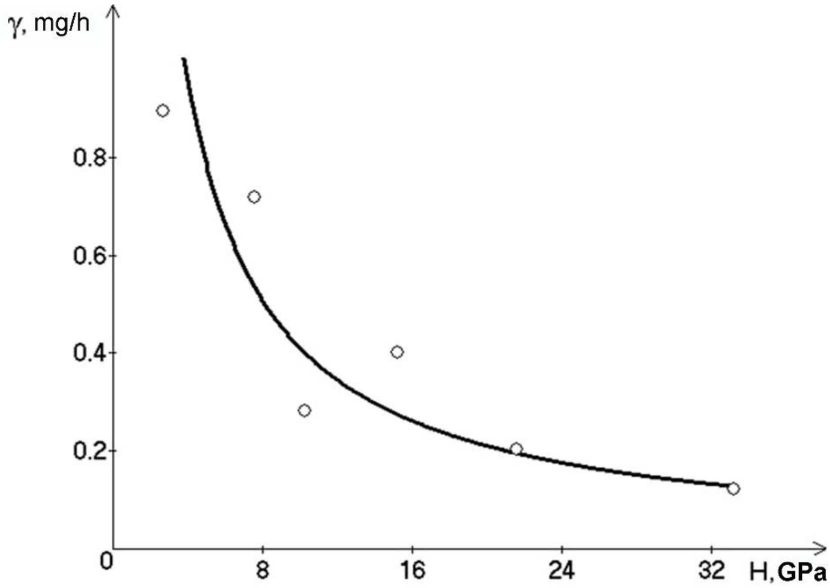

Fig. 1. Dependence of the change in the auger wear rate depending on the microhardness of the coating: actual ○, theoretical —

The results of the regression analysis are shown in Table 2, where cells with the maximum values of the correlation coefficient R for paired regression are marked in gray.

Table 2

The results of the regression analysis of the dependence of the change in the wear rate of the auger on the microhardness of the coating

N	Type of regression	Correlation coefficient R	N	Type of regression	Correlation coefficient R
1	$y = a + bx$	0.84993	9	$y = ax^b$	0.91600
2	$y = 1 / (a + bx)$	0.95706	10	$y = a + b \cdot \lg x$	0.93091
3	$y = a + b / x$	0.87496	11	$y = a + b \cdot \ln x$	0.93091
4	$y = x / (a + bx)$	0.95129	12	$y = a / (b + x)$	0.95705
5	$y = ab^x$	0.92861	13	$y = ax / (b + x)$	0.65429
6	$y = ae^{bx}$	0.92861	14	$y = ae^{b / x}$	0.78573
7	$y = a \cdot 10^{bx}$	0.92861	15	$y = a \cdot 10^{b / x}$	0.78573
8	$y = 1 / (a + be^{-x})$	0.46369	16	$y = a + bx^n$	0.73056

It was established that the wear rate of the auger decreases according to a hyperbolic pattern when the microhardness of the coating increases.

In the Fig. 2 shows the graphical dependence of the effect of the microhardness of the auger coating of the device for dehydrating municipal solid waste on the energy intensity of the process (when it wears out along the path s = 56850 m [15]), constructed using regularities (1-3).

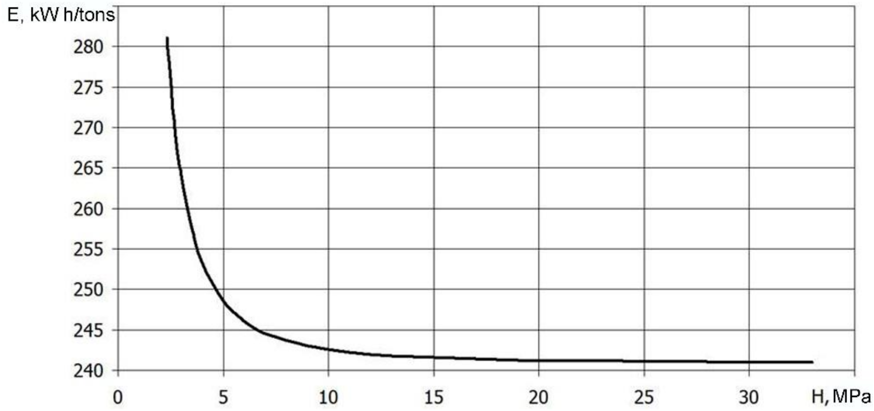

Fig. 2. The influence of the microhardness of the auger coating on the energy intensity of the municipal solid waste dehydration process after its operation and wear on the path *s* = 56850 m

From the Fig. 2 shows that after operation and wear on the path s = 56850 m during municipal solid waste (MSW) dehydration in the garbage truck, the increase in the microhardness of the auger coating from 2.7 GPa to 33.2 GPa leads to a decrease in energy consumption by 19 kWh/t or 12% and to reducing the cost of the solid waste dehydration process in the garbage truck, which indicates the importance of determining further ways to increase its wear resistance.

Conclusions

The hyperbolic dependence of the auger wear rate change depending on the microhardness of the coating was determined. It was established that after operation and wear on the path *s* = 56850 m during the dehydration of municipal solid waste (MSW) in a garbage truck, an increase in the microhardness of the auger coating from 2.7 GPa to 33.2 GPa leads to a decrease in energy consumption by 19 kWh/tons or 12% and to a decrease in price of the process of municipal solid waste dehydration in the garbage truck. Therefore, the determination of further ways of increasing the wear resistance of the auger require additional research.

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Березюк О.В., Савуляк В.І. , Харжевський В.О., Віштак І.В. Залежність швидкості зношування від мікротвердості покриття шнека зневоднення у сміттєвозі твердих побутових відходів

Стаття присвячена дослідженню впливу мікротвердості покриття шнека на його зносостійкість під час зневоднення твердих побутових відходів у сміттєвозі. Використання математичного апарату та відповідних програм регресійного аналізу дозволило визначити закономірність зміни швидкості зношування шнека залежно від мікротвердості покриття. Побудована графічна залежність зміни швидкості зношування шнека залежно від мікротвердості покриття, яка підтвердила достатню збіжність отриманої закономірності. Графіки впливу мікротвердості покриття шнека на швидкість його зношування демонструє доцільність її підвищення. Встановлено, що після експлуатації та зношування на шляху s = 56850 м під час зневоднення ТПВ у сміттєвозі збільшення мікротвердості покриття шнека з 2,7 ГПа до 33,2 ГПа призводить до зниження енергоємності на 19 кВт·год/т або 12% та до здешевлення процесу зневоднення ТПВ у сміттєвозі. Встановлена доцільність проведення додаткових досліджень з визначення подальших шляхів підвищення зносостійкості шнека.

Ключові слова: знос, зносостійкість, швидкості зношування, мікротвердість покриття, шнековий прес, сміттєвоз, зневоднення, тверді побутові відходи, регресійний аналіз.