Problems of Tribology, *V. 27, No 2/104-2022, 64-70*

Problems of Tribology
Website: http://tribology.khnu.km.ua/index.php/ProbTrib
E-mail: tribosenator@gmail.com

DOI: https://doi.org/10.31891/2079-1372-2022-104-2-64-70

The influence of the chemical composition of the hardened auger on its wear during dehydration process of municipal solid waste in the garbage truck

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Received: 09 April 2022: Revised: 15 May 2022: Accept: 02 June 2022

Abstract

The article is dedicated to the study of the influence of the chemical composition of the hardened auger by the chromium on its wear during dehydration of solid waste in the garbage truck. Using the rotatable central composition planning of the experiment of the second order by means of the Box-Wilson method, the dependencies of auger wear depending on the chemical composition of the hardened steel and friction path are determined. The responce surfaces of the objective functions are shown – the wearing of the hardened steel and energy consumption of the dehydration process by the hardened auger press of the mixed municipal solid waste according to the influense parameters. It is established that on the friction path s = 56850 m, during the dehydration process of solid waste in the garbage truck, the simultanuous incresing of the carbon content from 0.45% to 2.1%, and the chromium content – from 0.25% to 12%, at the optimum content of the manganese as 0.527% in the hardened steel of the auger, enable to decrease the energy consumption of the dehydration process of solid waste by 25.7 kWh/tons, or 10.7%. Therefore, it tends to cheaper the process of dehydration in the garbage truck. It is established the expediency of further research for the determination the rational composition and the structural state of the auger material and the ways to increase its wear resistance.

Key words: wear, chemical composition, hardening, auger press, garbage truck, dehydration, solid waste, regression analysis

Introduction

Among the important tasks of municipal engineering, one of the leading task is increasing of wear resistance and reliability of the machine parts. One of the promising technologies 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 that are alloyed by chromium and manganese is well-grounded. Such alloys hardened well and have high resistance to corrosion and abrasive wear. Therefore, the study of the influence of the chemical composition of the hardened steel of the auger on its wear during dehydration of municipal solid waste in the garbage truck is a topical task.

Literature review

In the paper [3], the results that were obtained in the operating conditions of extruders while processing of feed grain, with impurities of saponite mineral are presented. The results of experimental studies of wear resistance of different auger materials with different thermal and chemical-thermal treatment in corrosive-abrasive medium on special friction machines are included.

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.

In the paper [1] the influence of structure, phase composition and properties on abrasive wear resistance of chromium-manganese cast irons in the cast state was investigated. It is shown that the abrasion resistance of chromium-manganese cast irons is due to the microhardness of the matrix and austenitic carbide eutectic based on Me_7C_3 carbide, determined by the degree of alloying and shape parameter of eutectic carbide, and depends on deformation-phase transformations that occur in the process of testing for abrasive wear.

The article [4] shows the prospects of obtaining cost-effective alloyed manganese and chromium-manganese deposited metal that can be applied by surfacing on low-carbon steel without preheating. This is important for the industrial use of developed surfacing materials. It was also found that the highest wear resistance in different types of wear has a deposited metal with martensitic-austenitic and austenitic structures, and the presence of ferrite in the structure of the deposited metal reduces wear resistance.

By the authors of the the article [5], it was established 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**.**

In the article [6], 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.

The authors of the paper [7] 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.

In the article [8], 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. 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 resulls of 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.

The materials of the article [10] contains the research of the wearing 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 pericularities of 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.

Based on the planning of the experiment using the Box-Wilson method, the results of experimental research of the process of dehydration of municipal solid waste (MSW) in the garbage truck 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 paper [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 chromium alloying of 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 chromium content in the hardened material of the auger from 0.25% to 12% leads to a decrease the speed of the wearing an energy consumption of solid waste dehydration from 12.2% to 3.1%, and, consequently, to reduce the cost of dehydration in the garbage truck.

Purpose

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

Methods

The determination of the regularity of the wear of the screw depending on its chemical composition of the hardened steel and the friction path was carried out by means of a rotatable central composite planning experiment of a second order by the Box-Wilson method. The required coefficients were determined using the developed computer program "PlanExp" that is protected by a copyright registration certificate.

For the determination of the energy consumption of MSW dehydration, taking into account the auger wear, the following dependencies were used [13]:

$$\begin{aligned} E = {} & 1504 - 15.92 w_0 + 0.3214 \rho_0 - 1.069 n(u) - 2061 (\Delta_{aug} + u)/(D_{\min} - 2u) - 1947 (d_{\min} - \\ & -2u)/(D_{\min} - 2u) + 9.118 \cdot 10^{-4} w_0 \rho_0 + 0.002142 w_0 n(u) + 18.12 w_0 (\Delta_{aug} + u)/(D_{\min} - 2u) - \\ & -2.115 w_0 (d_{\min} - 2u)/(D_{\min} - 2u) + 4.392 \cdot 10^{-4} \rho_0 n(u) - 2.005 \rho_0 (\Delta_{aug} + u)/(D_{\min} - 2u) + \\ & +0.3361 \rho_0 (d_{\min} - 2u)/(D_{\min} - 2u) + 0.09031 w_0^2 - 7.923 \cdot 10^{-4} \rho_0^2 + 0.008241 n(u)^2 + \\ & +104172 [(\Delta_{aug} + u)/(D_{\min} - 2u)]^2 + 1318 [(d_{\min} - 2u)/(D_{\min} - 2u)]^2 \ [\text{kWh/tons}]; \end{aligned} \quad (1)$$

$$n = 52.43 - 1.276 \cdot 10^{-3} u^{1,5} \ [\text{rpm}], \quad (2)$$

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

Preliminary analysis [13, 14] of the results of experimental studies [3] showed that the wear of a hardened screw is a function of such 4 main parameters:

$$u = f(C_C, C_{Cr}, C_{Mn}, s), \quad (3)$$

where u – value of wear, μm; C_C, C_{Cr}, C_{Mn} – content of the carbon, chromium, manganese in the material of auger, consequently, in %; s – friction path, m.

The research of the influence of the mentioned factors on the wear of the hardened auger during the processing of the results of the single factor experiment by means of the regression analysis method, has

significant difficulties and large volume of calculations. Thus, in our opinion, it is better to conduct a multifactor experiment to obtain a regression equation for the response function – wear of the hardened auger by planning a multifactor experiment by the Box-Wilson method [15].

The values of the wear of the auger for a different chemical composition of hardened steel and the friction path are shown in the Table 1 [3].

Table 1

The wear of the auger for a different chemical composition of hardened steel and the friction path [3]

№	Material of the auger	Content in the auger material, %			Wear, μm, for the friction path, m			
		carbon	chromium	manganese	3000	6000	9000	12000
1	Steel 45	0.45	0.25	0.65	53	103	153	203
2	Steel У8	0.8	0.2	0.25	48	91	134	177
3	Steel ШХ15	1	1.5	0.3	43	80	116	152
4	Steel Х12	2.1	12	0.3	39	72	105	138

Based on the data shown in the Table 1, using rotatable central compositional planning of the second order of the experiment, using the developed software, protected by the copyright certificate, after discarding insignificant factors and effects of interactions by the Student's criterion, the regularity of screw wear depending on the chemical composition of its hardened steel and the friction path is determined:

$$u = 95 - 7.467C_C - 72.39C_{Cr} - 1782C_{Mn} + 0.0344s - 0.02148C_C s + \\ +0.00214C_{Cr} s - 0.01323C_{Mn} s + 352.5C_C^2 - 3.065C_{Cr}^2 + 2405C_{Mn}^2. \quad (4)$$

In the Fig. 1 it is shown the response surfaces of the objective function – the wear of the hardened auger u and its two-dimensional cross-sections in the planes of the impact parameters, plotted using regularity (4) that allow us to determine this relationship.

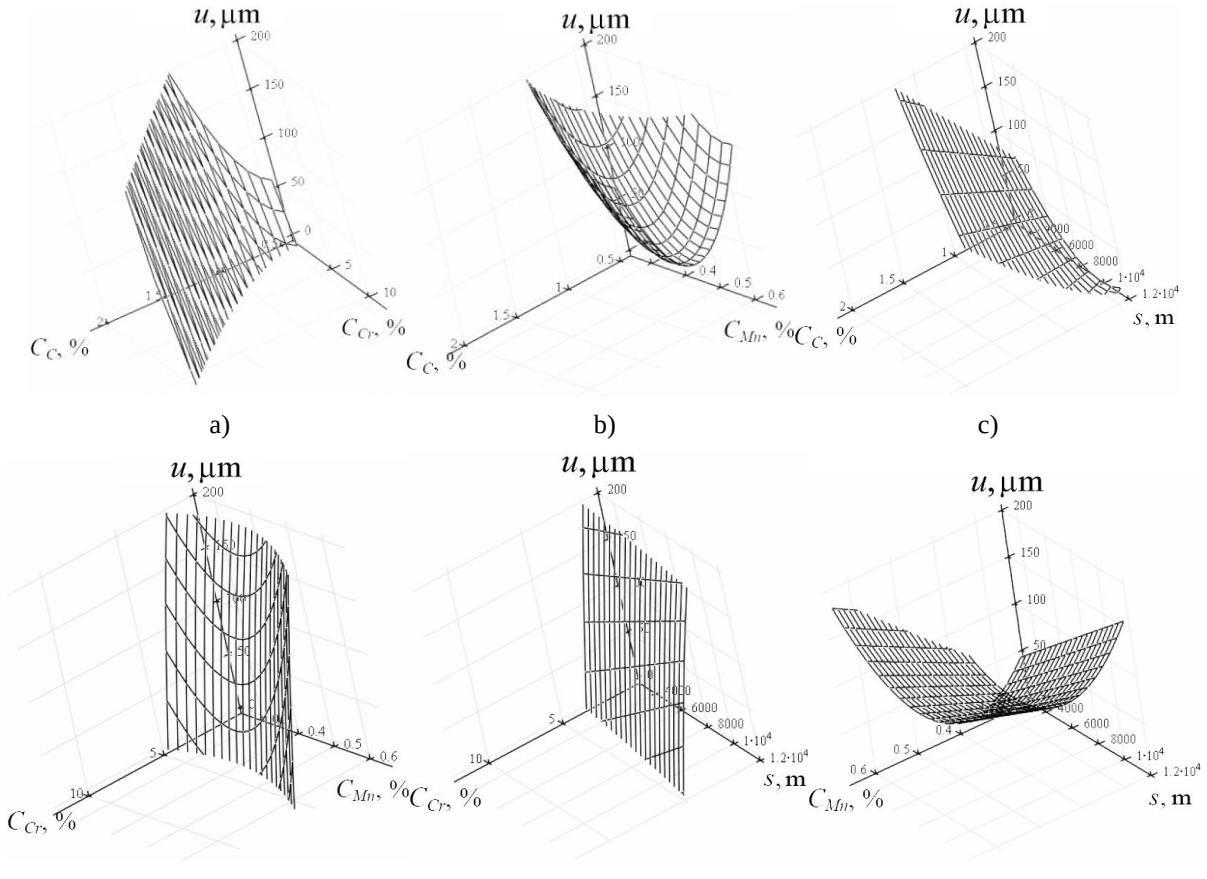
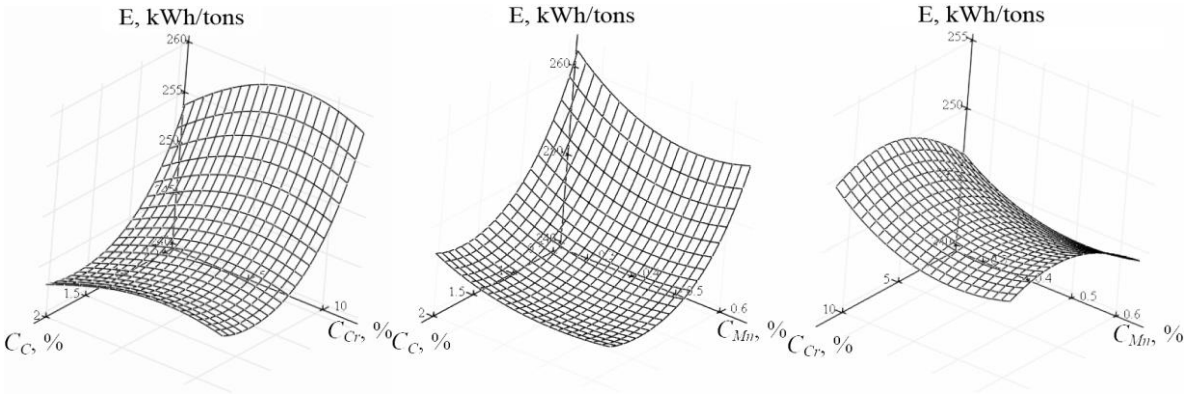


Fig. 1. The response surfaces of the objective function - wear of the hardened auger u in the planes of the impact parameters (a) – $u = f(C_C, C_{Cr})$, (b) – $u = f(C_C, C_{Mn})$, (c) – $u = f(C_C, s)$, (d) – $u = f(C_{Cr}, C_{Mn})$, (e) – $u = f(C_{Cr}, s)$, (f) – $u = f(C_{Mn}, s)$

It is established that according to Fisher's criterion the hypothesis about the adequacy of the regression model (4) can be considered correct with 95% reliability. The coefficient of multiple correlation was R = 0.999994 that indicates the high accuracy of the results.

According to Student's criterion, it was found that among the researched factors of influence (chemical composition of hardened steel) the most affected on the wear of the screw is the carbon content, and the least – the manganese content.

In the Fig. 2 the response surfaces of objective function – energy consumption of the process of dehydration by the hardened screw press of mixed municipal solid waste (when it wears during the way s = 56850 m [14]) and its two-dimensional cross sections in the planes of impact parameters (chemical composition of its hardened steel), that are plotted by means of regularities (1, 2, 4) and allow to illustrate the specified dependence are shown.



a) b) c)

Fig. 2. Response surfaces of the objective function - energy consumption E of the process of dehydration of the hardened screw press of mixed solid household waste in the planes of the parameters of impact after its operation and wear on the way s = 56850 m (a) – $E = f(C_C, C_{Cr})$, (b) – $E = f(C_C, C_{Mn})$, (c) – $E = f(C_{Cr}, C_{Mn})$

As shown on the Fig. 2, after operation and wear on the path s = 56850 m during dehydration of MSW in the garbage truck, the simultaneous increase the content of carbon from 0.45% to 2.1%, and chromuim from 0.25% to 12%, at optimal content of magnasese as 0.527% in the hardened steel of the auger leads to reduced energy consumption by 25.7 kWh/tons or 19.7% and to cheap the process of dehydration of MSW 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

According to Fisher's criterion, the regularity of auger wear from the chemical composition of its hardened steel and the friction path is determined. It is also established that according to Student's criterion, among the studied factors of influence (chemical composition of hardened steel), the most important effect on the wear of the auger is the carbon content, and the least – the manganese content.

The response surfaces of the objective functions – wear of hardened auger and energy consumption of the process of dehydration by the hardened auger press of mixed solid waste, and their two-dimensional cross sections in the planes of impact parameters that illustrate the dependence of these objective functions on individual impact parameters.

It is established that on the friction way s = 56850 m of the auger during dehydration of MSW in the garbage truck, the simultaneous increase the content of carbon from 0.45% to 2.1%, chromuim from 0.25% to 12%, at optimal content of magnasese as 0.527% in the hardened steel of the auger enable to reduce energy consumption by 25.7 kWh/tons or 19.7% and, therefore, to cheap the process of dehydration of MSW in the garbage truck. Thus, 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 needs to conduct the further researches.

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

Анотація

Стаття присвячена дослідженню впливу хімічного складу гартованого шнека на його знос під час зневоднення твердих побутових відходів у сміттєвозі. За допомогою використання ротатабельного центрального композиційного планування експерименту другого порядку методом Бокса-Уілсона визначено закономірність зносу шнека залежно від хімічного складу його гартованої сталі та шляху тертя. Показано поверхні відгуків цільових функцій – зносу гартованого шнека та енергоємності процесу зневоднення гартованим шнековим пресом змішаних твердих побутових відходів в площинах параметрів впливу. Встановлено, що на шляху зношування шнека s = 56850 м під час зневоднення твердих побутових відходів у сміттєвозі одночасне збільшення вмісту вуглецю з 0,45% до 2,1%, хрому з 0,25% до 12% при оптимальному вмісті марганцю 0,527% в гартованій сталі шнека дозволяє зменшити енергоємність зневоднення твердих побутових відходів на 25,7 кВт·год/т або 10,7%, а, отже, і до здешевлення процесу їхнього зневоднення у сміттєвозі. Виявлено доцільність проведення подальших досліджень з визначення раціонального складу і структурного стану матеріалу шнека та шляхів підвищення його зносостійкості.

Ключові слова: знос, хімічний склад, гартування, шнековий прес, сміттєвоз, зневоднення, тверді побутові відходи, планування експерименту.