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The influence of alloying with manganese and chromium of steel hardened and tempered auger on its relative wear resistance during dehydration in a municipal solid waste truck

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Abstract

The article is dedicated to the study of the influence of alloying with manganese and chromium followed by hardening and tempering of the auger on its wear resistance during the dehydration of municipal solid waste truck. The use of a mathematical apparatus and appropriate regression analysis programs made it possible to determine the dependence of the wear resistance of the auger on the content of manganese and chromium in the steel of the auger for the case of its quenching and tempering. Constructed graphical dependences of relative wear resistance with the indicated alloying and heat treatment of the screw revealed a significant influence of the concentration of manganese and chromium in steel, sufficient convergence of the obtained patterns was confirmed. It was established that after operation and wear on the path s = 56850 m during the dehydration of solid waste in a garbage truck, an increase in the manganese content in the steel of the heat-treated screw from 0.32% to 1.8% leads to a decrease in energy intensity by 10 kWh/tons, and an increase chromium content in screw steel after similar heat treatment from 0% to 6% leads to a decrease in energy consumption by 11.5 kWh/tons and to a reduction in the cost of the solid waste dehydration process in the garbage truck. It was determined that tempering the chromium-manganese screw steel after its hardening allows reducing energy consumption by 1.26...2.56 kWh/tons, depending on the chromium content. The expediency of conducting further research on determining the rational composition and structural state of the auger material and ways to increase its wear resistance has been revealed

Key words: wear, wear resistance, manganese content, chromium content, tempering, auger press, garbage truck, dehydration, municipal solid waste, regression analysis.

Introduction

Increasing the wear resistance and reliability of operative links of machines occupies a prominent place among the important tasks of municipal machinebuilding [1, 2]. A promising technology for the primary processing of municipal solid waste (MSW), aimed at reducing both the costs of transporting solid waste and the negative impact on the environment, is their dehydration during the process of loading into a garbage truck, which is done by accompanying processes of preliminary compaction and partial grinding.

Dehydration of MSW in the garbage truck is carried out with the help of a conical auger, the surfaces of which are intensively worn. This is due to the presence in the waste of small metal products, glass, ceramics, stones, bones, polymer materials that have abrasive properties. In addition, the moisture occuring in MSW in the range of 39...92% by mass forms an aggressive corrosive environment. As a rule, alloyed iron alloys are used for the production of screws. The use of steels and cast iron alloyed with chromium and manganese is justified [3]. Such alloys are well amenable to heat treatment and have high resistance against corrosive and abrasive wear. Therefore, the study of the influence of the content of manganese and chromium in the steel of the auger, the manufacturing technology of which includes quenching and tempering operations, on its relative wear resistance during the dehydration of s municipal solid waste in a garbage truck is an urgent task.

Analysis of recent research and publications

The analysis of the influence of the main alloying and modifying elements on the properties of wear-resistant steels is carried out in the article [3]. It has been established that manganese in steel after tempering at 760 °C with an increase in its content to 1.8% contributes to an increase in the degree of dispersion of pearlite, while the amount of pre-eutectic ferrite or, accordingly, post-eutectic carbides decreases. A further increase in the manganese content is undesirable due to a decrease in the plasticity of the steel, but the strength increases. It is noted that chromium is the most common element that is introduced into manganese steel in order to increase wear resistance. It stabilizes austenite and is also an active carbide former. When 1% Cr is introduced into steel, the relative wear resistance increases significantly (from 1.0 to 1.32). But even with the addition of 3% Cr, the impact toughness decreases. Therefore, steel with approximately 2% Cr has the most satisfactory set of properties.

In the paper [1], a study of the influence of structure, phase composition, and properties on the abrasive wear resistance of chromium-manganese cast irons in the cast state was carried out. It is shown that the abrasive wear resistance of chromium-manganese cast irons is determined by the microhardness of the matrix and the austenite-carbide eutectic based on Me7C3 carbide, is determined by the degree of alloying and the shape parameter of the eutectic carbide, and also depends on the deformation-phase transformations that occur during abrasive wear tests.

The materials of the article [4] show the prospects of obtaining an economically alloyed manganese and chromium-manganese surfacing metal, which can be deposited by surfacing on low-carbon steel without preheating, which is important for the use of developed surfacing materials in industry. It was also established that the highest wear resistance for various types of wear is provided by the superimposed metal with martensitic-austenitic and austenitic structures, while the presence of ferrite in the structure of the superimposed metal reduces the wear resistance.

A mathematical model for calculating the rate of wear of triboelements in the tribosystem under conditions of corrosive-abrasive wear was proposed by the author of the work [5]. The input factors were: active acidity, abrasiveness, roughness, load and sliding speed. The degree of influence of the above factors on the rate of wear has been theoretically determined: abrasiveness is the most important factor, followed by the level of active acidity and load in descending order of influence

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

The authors of the work [7] note that wear-resistant steels should have high strength, fracture toughness, thermal conductivity, and the ability to form strong films of secondary structures during friction. In the presence of aggressive environments, elevated temperatures, and the action of other physical and chemical factors that reduce surface strength, wear resistance depends on the corrosion resistance of the material, its heat resistance, and other properties

The influence of geometric parameters on the performance and design of a briquetting machine using a pressure model based on the theory of piston flow is studied in the article [8]. An analytical model using a pressure model was also developed based on Archard's wear law to investigate the wear of biomass briquetting machine screws. The developed model satisfactorily predicted the wear of the screw and showed that the speed of rotation and the choice of material have the greatest influence on it. The amount of wear increases exponentially towards the end of the screw, where the pressure is highest. Changing the auger design to select the optimal geometry and speed with appropriate material selection can increase auger life and biomass briquetting machine performance.

In the paper [9], it was established that the greatest strengthening after high-temperature thermomechanical treatment with a simultaneous significant increase in its strength limit is observed in steels with a troostite structure, since the factor of reducing the size of austenite grains contributes to a significant increase in the strength of steels. The strengthening of steel in this structural state reaches its maximum value after doping with 1...2% chromium. When the chromium content is further increased to 5%, the strengthening effect remains unchanged.

Combined treatment, consisting of a combination of methods of alloying 1...5% chromium and high-temperature thermomechanical treatment, can be recommended for practical use as an effective means of increasing the strength of steels, but it is not recommended to be used as a means of increasing wear resistance in conditions of sliding friction on a monolith.

In the materials of the article [10], the wear of a double-auger extruder of rigid PVC resins was investigated. The pressures around the cylinder during the extrusion of two rigid PVC resins in a laboratory extruder with a diameter of 55 mm were measured and the forces acting on the screw core were determined. Numerical modeling of the flow was carried out using power-law functions of resin viscosity.

The main features of the process of pressing wood shavings in screw machines are studied in [11]. The processes that take place in different sections of the screw are established, formulas are defined, the use of which allows you to calculate the loads acting on the turns of the screw, as well as determine the pressing power. Specific energy consumption and the degree of heating of raw materials during pressing are established.

The results of experimental studies of the solid waste dehydration process, obtained on the basis of planning the experiment using the Box-Wilson method, are given in [12]. By means of rotatable central composite planning, quadratic regression equations with 1st-order interaction effects were obtained for the objective functions: moisture and density of pre-compacted and dehydrated MSW, maximum drive motor power, energy consumption of MSW dehydration. This made it possible to determine the optimal parameters of the dehydration equipment (rotation frequency of the auger, the ratio of the radial gap between the auger and the body, as well as the ratio of the diameter of the auger core to the outer diameter of the auger on the last turn) for mixed and "wet" solid waste, according to the criterion of minimizing the energy intensity of the process.

In the the article [13], an improved mathematical model of the operation of the solid waste dehydration drive in the garbage truck is proposed, taking into account the wear of the auger, which made it possible to determine with the help of a numerical study of the dynamics of this drive during start-up that with increasing wear of the auger, the pressure of the working fluid at the inlet of the hydraulic motor of the drive increases, and the angular speed and rotation frequency of the screw are significantly reduced with constant supply of 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 found that the wear of the auger by 1000 μm leads to an increase in the energy intensity of solid waste dehydration by 11.6%, and, therefore, to an increase in the cost of their dehydration in the garbage truck and acceleration of the wear process.

By means of regression analysis, the influence of chromium alloying of the hardened steel of the auger on its wear during the dehydration of solid waste in a garbage truck was investigated [14], and it was also established that during the operation and wear of the auger on the path s = 56850 m during the dehydration of solid household waste in the garbage truck, an increase in the content of chromium in the hardened material of the auger from 0.25% to 12% allows to reduce the rate of wear and energy consumption of dehydration of municipal solid waste from 12.2% to 3.1%, and, therefore, to reduce the cost of the process of their dehydration in the garbage truck.

Aim of the articles

Study of the effect of manganese and chromium content in the steel of the auger after tempering on its relative wear resistance during the dewatering of solid household waste in a garbage truck.

Methods

The determination of paired dependences of the relative wear resistance of the auger from the content of manganese and chromium after quenching and tempering was carried out by the method of regression analysis [15]. Regressions were determined on the basis of linearization transformations, which allow to reduce the non-linear dependence to a linear one. The coefficients of the regression equations were determined by the method of least squares using the developed computer program "RegAnaliz", which is protected by a certificate of copyright registration.

To determine the energy intensity of solid waste dehydration, taking into account the wear of the auger, the following laws were used [13]:

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

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

where E is the energy intensity of solid waste dehydration, kWh/t; ρ_0 – initial solid waste density, kg/m3; w_0 – initial relative humidity of solid waste, %; n – nominal auger rotation frequency, *rpm*; u – auger wear, *m*; Δ_{aug} – radial clearance between the screw and the housing, *m*; D_{min} is the outer diameter of the screw on the last turn, *m*; d_{min} – the diameter of the screw core on the last turn, *m*.

The values of the relative wear resistance of steel after tempering for different values of the content of alloying elements: manganese and chromium are given in the Table 1 and Table 2 [3].

Table 1

Effect of manganese content on the relative wear resistance of steel after tempering [3]

Manganese content, %	0,32	0,68	1,11	1,35	1,8
Relative wear resistance	1	1,18	1,11	1,2	1,26

Table 2

The effect of chromium content on the relative wear resistance of steel after tempering [3]

Chromium content, %	0	1	2	3	6
Relative wear resistance	1	1,32	1,5	1,61	1,62

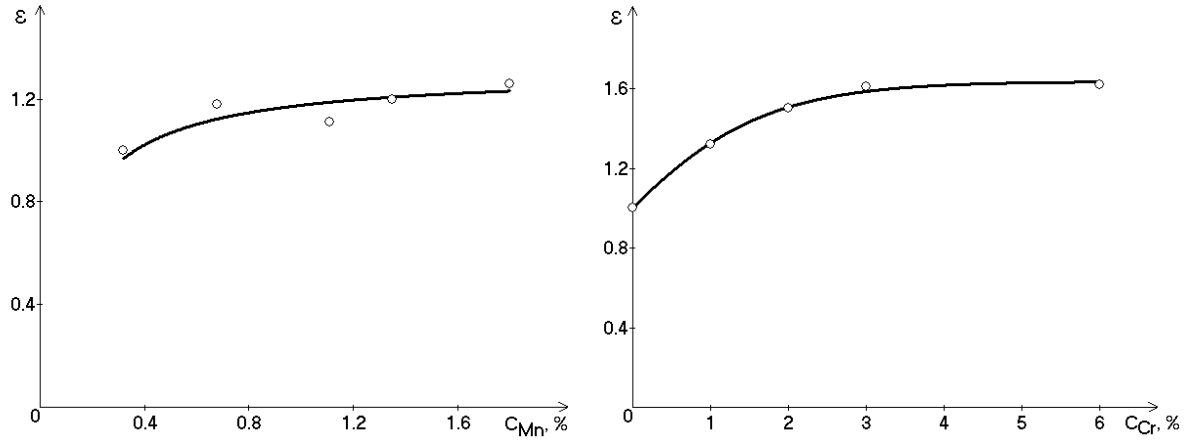
As a result of the regression analysis of the data in the Table 1 and Table 2, the dependences of the relative wear resistance of the auger depending on the content of manganese and chromium in its steel after tempering are determined:

$$\varepsilon = \frac{C_{Mn}}{0{,}08605 + 0{,}7642 C_{Mn}}; \tag{3}$$

$$\varepsilon = \frac{1}{0{,}6113 + 0{,}3897 e^{-C_{Cr}}}, \tag{4}$$

where ε is relative wear resistance; C_{Mn} – manganese content in the screw material, %; C_{Cr} – chromium content in the screw material, %.

Fig. 1 shows graphical dependences of the relative wear resistance of the screw depending on the content of manganese and chromium in its steel after tempering, constructed using dependences (3, 4), which confirm the sufficient convergence of the obtained patterns compared to the data given in Table 1.



a) **b)**

Fig. 1. The relative wear resistance of the screw depending on the content of alloying elements in its steel after tempering the steel (a) – manganese, (b) – chromium: actual ○, theoretical —

The results of the regression analysis are shown in Table 3, where cells with the maximum values of the correlation coefficient *R* for each of the paired regressions are marked in gray.

It was established that the relative wear resistance of the auger after tempering increases according to a hyperbolic dependence with an increase in the manganese content and an exponential dependence with an increase in the chromium content.

In the Fig. 2 are shown the graphical dependences of the influence of the manganese and chromium content in steel after the auger of the solid household waste dehydration device has been released on the energy intensity of the process (when it wears out along the path s = 56850 *m* [14]), constructed using dependences (1-4).

Table 3

The results of the regression analysis of the dependence of the relative wear resistance of the auger depending on the content of manganese and chromium in its steel after tempering

№	Type of regression	Correlation coefficient R		№	Type of regression	Correlation coefficient R	
		$\varepsilon=f(C_{Mn})$	$\varepsilon=f(C_{Cr})$			$\varepsilon=f(C_{Mn})$	$\varepsilon=f(C_{Cr})$
1	$y = a + bx$	0.84446	0.81748	9	$y = ax^b$	0.87408	0.91249
2	$y = 1 / (a + bx)$	0.83369	0.76931	10	$y = a + b\cdot\lg x$	0.87074	0.88508
3	$y = a + b / x$	0.87157	0.88513	11	$y = a + b\cdot\ln x$	0.87074	0.88543
4	$y = x / (a + bx)$	0.99587	0.99907	12	$y = a / (b + x)$	0.83369	0.76931
5	$y = ab^x$	0.83932	0.79422	13	$y = ax / (b + x)$	0.89122	0.93566
6	$y = ae^{bx}$	0.83932	0.79422	14	$y = ae^{b / x}$	0.88186	0.91253
7	$y = a \cdot 10^{bx}$	0.83932	0.79422	15	$y = a \cdot 10^{b / x}$	0.88186	0.91253
8	$y = 1 / (a + be^{-x})$	0.86049	0.99935	16	$y = a + bx^n$	0.80388	0.62168

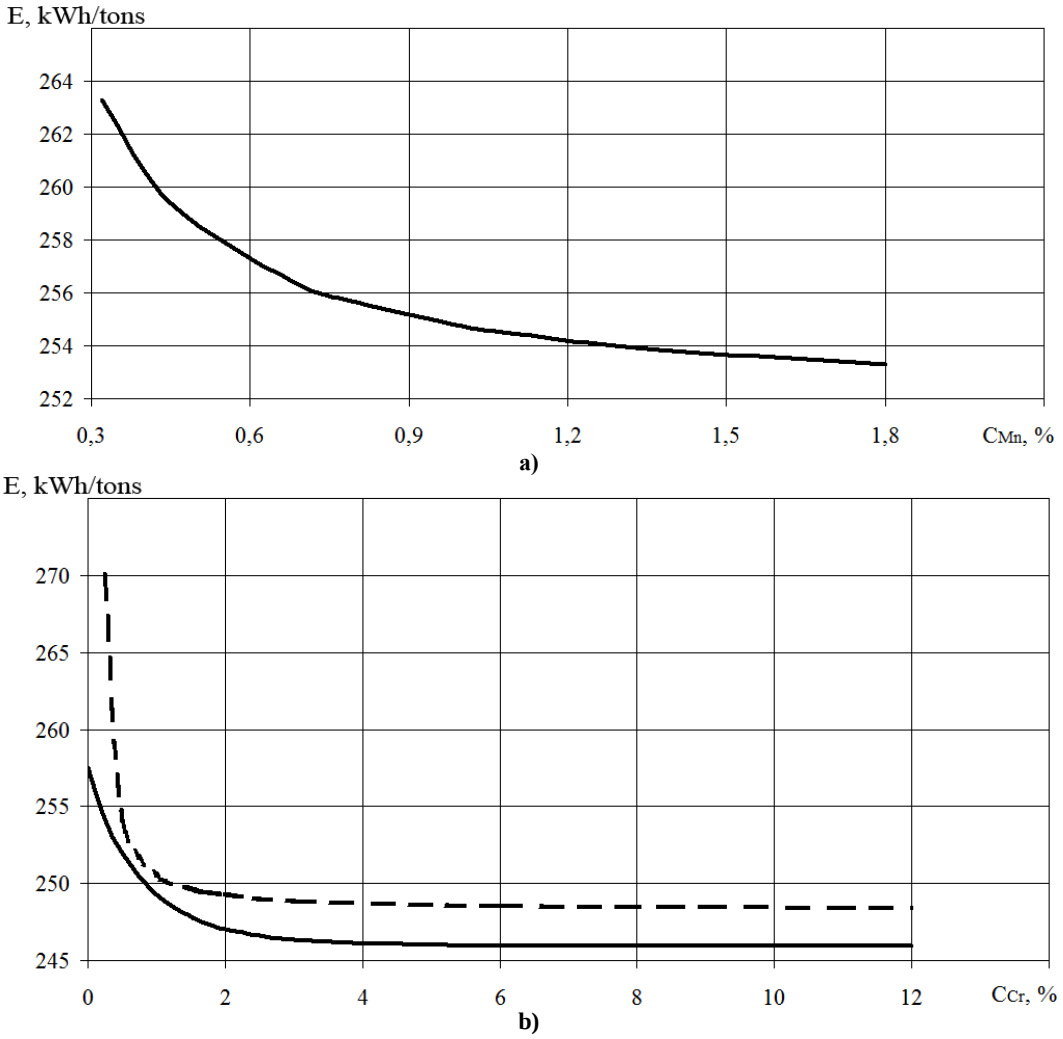


Fig. 2. The influence of an increase in the content of alloying elements in the steel of the auger after tempering on the energy intensity of the solid waste dehydration process after its operation and wear on the path s = 56850 m (a) – manganese, (b) – chromium

From the Fig. 2, it can be seen that after operation and wear on the path s = 56850 m during the dehydration of solid waste in the garbage truck, the increase in the manganese content in the auger steel after tempering from 0.32% to 1.8% leads to a decrease in energy intensity by 10 kWh/tons or 3.8%, increasing the chromium content in the auger steel after tempering from 0% to 6% leads to a decrease in energy intensity by 11.5 kWh/tons or 4.8% and to a reduction in the cost of the solid waste dehydration process in the garbage truck. In addition, the comparison in Fig. 2, *b* of the energy capacity of the screw steel after tempering (solid line) with the energy capacity of the hardened screw steel determined in [14] (dashed line) showed that the tempering of the screw steel after its hardening allows reducing the energy capacity by 1.26...2.56 kWh/tons depending on the

chromium content, which indicates the importance of determining the rational composition and structural state of the material of the friction surfaces of the screw and ways to increase its wear resistance.

Conclusions

The dependences of the relative wear resistance of the auger from the content of manganese and chromium in its steel after tempering have been determined. It was found that after operation and wear on the path s = 56850 m during the dehydration of solid waste in a garbage truck, an increase in the manganese content in the auger steel after tempering from 0.32% to 1.8% leads to a decrease in energy intensity by 10 kWh/tons or 3.8%, increasing the chromium content in the auger steel after tempering from 0% to 6% leads to a decrease in energy consumption by 11.5 kWh/tons or 4.8% and to a reduction in the cost of the solid waste dehydration process in the garbage truck. It was determined that the tempering of the auger steel after its hardening allows reducing the energy consumption by 1.26...2.56 kWh/tons depending on the chromium content. Therefore, the determination of the rational composition and structural state of the material of the friction surfaces of the auger and ways of increasing its wear resistance require further research.

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Березюк О.В., Савуляк В.І., Харжевський В.О. Вплив легування марганцем та хромом сталевого загартованого з відпуском шнека на його відносну зносостійкість під час зневоднення у сміттєвозі ТПВ.

Анотація

Стаття присвячена дослідженню впливу легування марганцем та хромом з наступним гартуванням та відпуском шнека на його зносостійкість під час зневоднення твердих побутових відходів у сміттєвозі. Використання математичного апарату та відповідних програм регресійного аналізу дозволило визначити залежність зносостійкості шнека від вмісту марганцю та хрому в сталі шнека для випадку його гартування з відпуском. Побудовані графічні залежності відносної зносостійкості із вказаним легуванням та термообробкою шнека виявили значний вплив концентрації марганцю та хрому в сталі, підтверджено достатню збіжність отриманих закономірностей. Графіки впливу легування марганцем та хромом сталевого шнека з наведеною термообробкою на енергоємність зневоднення твердих побутових відходів демонструють її доцільність. Встановлено, що після експлуатації та зношування на шляху s = 56850 м під час зневоднення ТПВ у сміттєвозі збільшення вмісту марганцю в сталі термообробленого шнека з 0,32% до 1,8% призводить до зниження енергоємності на 10 кВт·год/т, а збільшення вмісту хрому в сталі шнека після аналогічної термообробки з 0% до 6% призводить до зниження енергоємності на 11,5 кВт·год/т та до здешевлення процесу зневоднення ТПВ у сміттєвозі. Визначено, що відпуск хромо-марганцевої сталі шнека після її гартування дозволяє зменшити енергоємність на 1,26...2,56 кВт·год/т залежно від вмісту хрому. Виявлено доцільність проведення подальших досліджень з визначення раціонального складу і структурного стану матеріалу шнека та шляхів підвищення його зносостійкості.

Ключові слова: знос, зносостійкість, вміст марганцю, вміст хрому, відпуск, шнековий прес, сміттєвоз, зневоднення, тверді побутові відходи, регресійний аналіз.