Problems of Tribologyy, 24 (3/93) (2019) 14-21

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

DOI: https://doi.org/10.31891/2079-1372-2019-93-3-14-21

Increasing the durability of working elements of equipment for abrasive-containing masses processing

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Abstract

The operating parameters of modern equipment for transportation, mixing and pressing of an abrasive-containing masses are examined. The main wear modes are determined to which the working surfaces of the specified equipment are exposed during its operation. The list of main materials of which the working elements of the considered equipment are made, as well as the list of the main serial surfacing materials used for their hardening are shown. The mechanism of abrasive wear of coatings based on W_2C – WC and coatings based on TiB_2 – TiC was investigated.

Key words: wear-resistant coatings, abrasive wear, transporting, mixing, pressing, tungsten carbide, titanium carbide, titanium diboride.

Introduction

One of the important tasks of the whole list of industries is to increase the wear resistance of the working elements of machines and mechanisms operating under the conditions of intensive abrasive wear, which is the most common and destructive type of mechanical wear. Such industries include: mining, oil and gas, energy, metallurgy, woodworking, construction, agriculture, etc. where the working surfaces of machines and mechanisms are in direct contact with the material being processed and, in most cases, with the mineral environment.

The issue of increasing the durability of the working elements of equipment for the transportation, mixing and pressing of abrasive-containing masses is connected with the study of the patterns, nature and features of the abrasive wear mechanism. This opens the perspectives of developing reasonable measures to increase the reliability of such equipment, including method of strengthening its working surfaces since long-term use of the equipment under conditions of intensive abrasive wear leads to a decrease in performance, which causes a deterioration in the quality of the original products.

Formulation of the problem

Currently, in most cases, the modes of operation of modern equipment for the transportation, mixing and compression of abrasive and abrasive-containing masses have been brought to the forced ones, which are larger at times, and in some cases by an order of magnitude, compared to the traditional ones, for example:

- in conjunction with traditional industrial mixers with a 90 … 120 min^{-1} rotation speed of blades turbo mixers with a 800 … 1600 min^{-1} rotational speed are used;
- wet pressing of raw bricks with the use of modern vacuum presses implies a working pressure of compression of 25 … 28 MPa, whereas this figure for the presses of the previous generation was only 1,8 … 2,5 MPa;
- while dry pressing of building ceramics the pressures reaches 30 MPa;
- production of fuel briquettes involves working pressures in the pressing zone of 20 … 35 MPa;
- production of fuel granules (pellets) is carried out at a working pressure in the pressing zone of 30 … 40 MPa [1];

- production of compound feeds with extrusion involves working pressures in the pressing area of 8 … 10 MPa;
- the pressures of the abrasive masses while manufacturing of an abrasive tool, reaches 75 MPa.

Thus, the growth of power and speed modes of operation of equipment for transportation, mixing and pressing of abrasive-containing masses necessitates the increasing of durability of the working elements of the abovementioned equipment.

Purpose

The purpose of this work is to analyze the main wear mechanisms of working elements of modern equipment for processing abrasive-containing masses on the basis of the analysis of the parameters of their operation. Review of the most used materials for the manufacture of the working elements of the considered equipment, as well as the analysis of the perspectives of using surfacing materials for their strengthening.

Literature review

Continuous tendencies to minimize equipment and structure of the technological cycle in most of the abovementioned examples involves the dynamic transformation of the movable abrasive mass in contact with the working surfaces of the equipment, first to a less mobile, and in the final stage - almost motionless, often related to monolithic abrasive. Under these conditions, the abrasive particles partially reduce their mobility and cannot freely push off and scroll in the process of contact with the work surfaces, which causes an increasing in the intensity of abrasive wear. Confirmation of the abovementioned statements are images of worn surfaces of working elements of high-performance technological equipment for transportation, mixing and pressing of abrasive-containing masses (Fig. 1).

The authors of [2 - 3] indicate that the conditions of wear due friction in the abrasive mass are different from the conditions of friction over the monolithic abrasive, primarily due to the external force on the contact surface. However, the micro-cutting and deforming action of a single abrasive particle remains an elemental component of the wear mechanism.

Since the abrasive particle in the mass is pushed with the detail from the path of motion, the force at the point of contact will be determined by the speed of movement of the part in the abrasive mass, the density of this mass, the size and hardness of its particles. In the case of wear in the abrasive mass, it is more difficult to create and control the stability of the external force at the contact of the interaction of the abrasive particle and the wear surface [3 - 4].

Considering the fracture mechanisms of the friction surface of a metal that interacts with sliding in the abrasive mass, it is necessary to emphasize the importance of the level of active abrasive particles fixation in the mass. On the one hand, the higher the degree of fixation, the more likely it is to scratch; on the other hand, the mobility of the abrasive particles, which should allow the inflow of sharp particles to replace the blunt ones, is quite important. The results of studies [5] show the efficiency of particle mobility for the intensification of abrasive fracture.

Brittle, solid, practically not charged materials that can wear out in the abrasive environment of more hard, brittle and strong particles were particularly considered. The process of grinding this materials corresponds to the process of wear over time.

In [2, 5 - 6] the main factors influencing the process of abrasive wear are highlighted:

- nature and form of structural components of the alloy;
- nature and hardness of the abrasive material;
- the degree of bonding of the abrasive particles;
- pressure on the abrasive particle.

It is experimentally established that the mechanism of abrasive wear is determined mainly by the ratio of the hardness of the metal and the hardness of the abrasive particles, and it is necessary prerequisite for its manifestation is the predominant hardness of the wearing body compared with the wear one [3].

Studies [3, 7] found that the dependence of the wear resistance on the hardness of material is directly proportional only in the case of micro-cutting and plastic deformation, as well as when the abrasive particles remain stationary and there are no following factors: destruction of abrasive particles, strong surface heating and impact on the material of an aggressive environment. A special consideration is given to the situation when, under actual operating conditions, abrasive particles have the form of a moving abrasive mass, which is rubbed in the gaps between the contacting surfaces. As a result, scratches are formed on the work surfaces of the parts, occurs elastic-plastic deformation of the surface layer as well as occurs fatigue destruction of the surfaces.

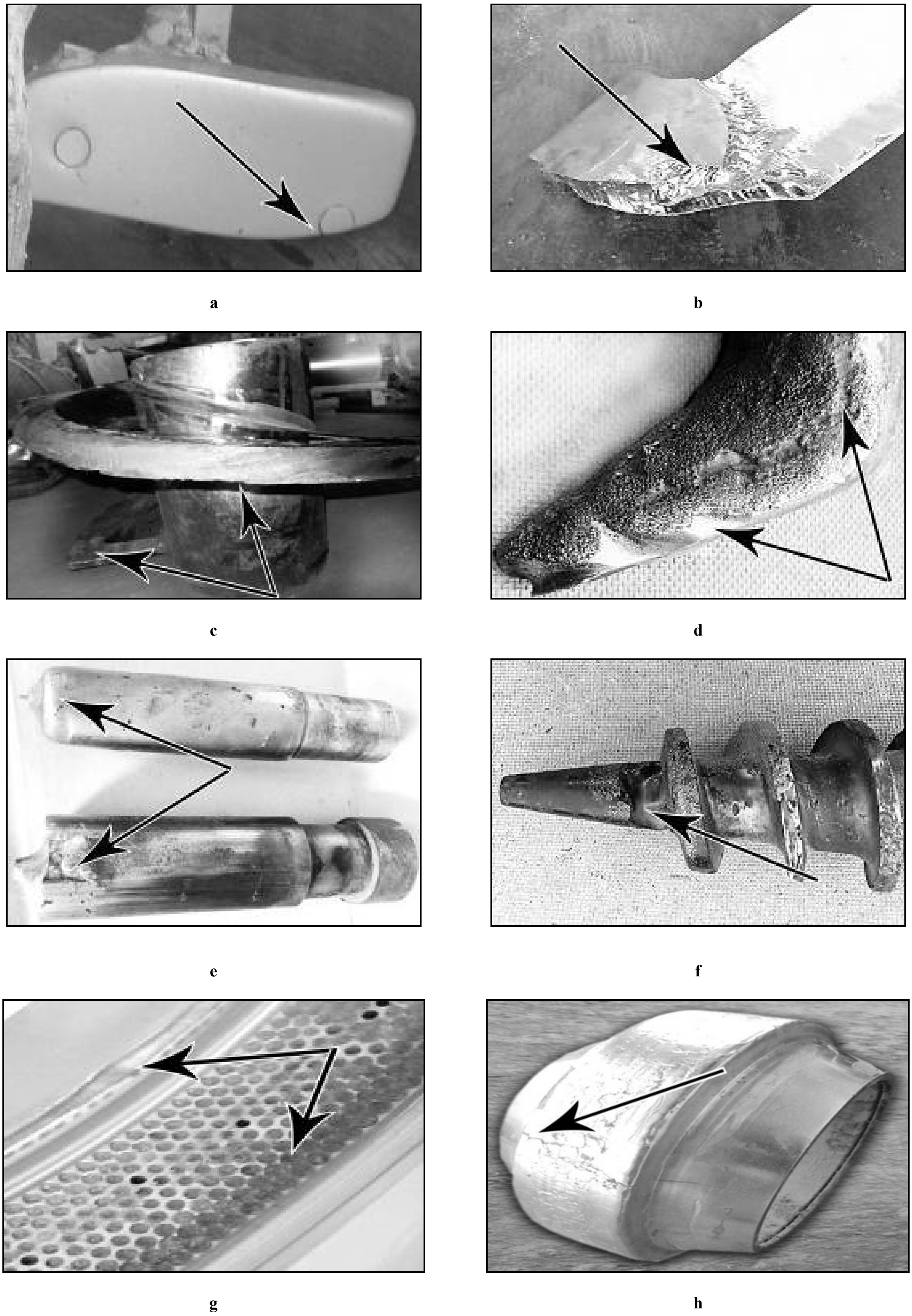


Fig. 1. Appearance of worn work surfaces of equipment for processing abrasive materials (arrows indicate the characteristic manifestations of abrasive wear):
a – blade of the concrete mixer;
b –a fragment of the turbine mixer blades for the manufacture of dry compounds;
c – section of a auger of vacuum press for the manufacture of construction ceramics;
d – fragment of the blade of the mixer for the manufacture of particleboard;
e – punches for sawdust briquetting press for the manufacture of fuel briquettes;
f – auger of a sawdust briquetting press for production of fuel briquettes;
g – a fragment of a pellet press matrix;
h – roll of pellet press

Tenenbaum M.M. indicates [8] that the contact of the abrasive particle with the friction surface contained in the abrasive mass is carried out on a relatively small area where maximum stresses may occur, which depending on the radius of curvature of the abrasive particle projection, normal compression force and strength of the abrasive particle. In addition, it is necessary to take into account the tangential force that determines the attachment of the abrasive particles among other particles, namely the average internal friction coefficient in the abrasive mass.

In general, the positive effect of the hardness of the material on its wear resistance is most evident in the first stage of abrasive wear, when the abrasive particle is immersed in the surface of the material. Mainly, the compression stresses characteristic of the force of the indenter in the process of determining the hardness by any of the known methods [2], operate under the contour of contact of a single abrasive particle with the wear surface. Therefore, the higher the hardness of the material, the lower the depth of immersion of the abrasive particles. In [9], this dependence is given taking into account the properties of the abrasive and the interaction conditions:

$$h = \sqrt{\frac{p}{c\eta HV}}, \tag{1}$$

where h – immersion depth of the abrasive particle;

p – specific load;

C – a dimensionless coefficient that depends on the shape of the abrasive particle;

η –number of abrasive particles per unit area of the abrasive surface;

HV – hardness of the metal.

The use in this formula of the coefficient c characterizing the state of the abrasive is justified, since the shape of the abrasive particles (with blunt or sharp peaks), the strength and roughness of the material, the size of the free abrasive particles will significantly affect their abrasive ability, and therefore, their durability and friction surfaces [2, 9].

In the second stage of abrasive wear, the picture of the stress state at the contact is more complicated than under the indenter in the process of determining the hardness. In the metal which is in contact with the abrasive particles there are tensile, compression, shear stresses namely the resistance of metal becomes complex. Depending on the properties of the abrasive and metal, last undergoes various destruction in the movement of the abrasive particle. The metal can be removed from the wear surface by micro-cutting with abrasive particles, crumble with a brittle fracture, pushes into the heaps by scratching, undergoing considerable deformation in this case. In the first two cases, the separation of the metal passes through a single passage of the abrasive particle, in the other two cases the separation of the material passes through repeated re-deformation of metal volumes that are displaced from the scratch with fatigue. In the conditions of abrasive wear, all types of friction surface destruction develop under the determining influence of one of the considered mechanisms.

Considering the separation of metal with an abrasive particle as a kind of mechanical fracture, it is need to determine the decisive role of strength in the process of abrasive wear. The value of strength in the mechanism of abrasive wear of steels is considered in [2, 10 - 11]. The dependence of the wear resistance of steel on its hardness and strength limit is established. At constant hardness values ≤ 50 HRC, a significant change in the tensile strength does not affect the durability.

Results

The mechanism of abrasive wear, which is difficult while contacting the wear particle with steels, is further complicated for deposited coatings, which are characterized by pronounced heterogenous structure [6, 12]. At the macro level, the mechanisms of abrasive wear of steels and alloys are similar, which allows to use knowledge of the basic patterns of steel wear while developing and predicting the wear resistance of alloys.

Thus, the destruction of the surface layer of the working elements of equipment for processing abrasive-containing masses is cyclical, the period of which is determined by the composition of the processing mass and the contact-force conditions of interaction in each case. It should be noted that the periodic nature of the formation and destruction of chemically modified surface layers under real friction conditions is local (at each site of the friction surface). Due to the discreteness of the contact, the heterogeneity of the load plot in time and in spatial coordinates in different parts of the friction surface, different phases of locally periodic processes occur simultaneously. This leads to smoothing of the periodicity and dynamic equilibrium of the processes of formation and destruction of surface oxide structures due to the physic-statistical distribution of locally periodic processes.

The most of the damage to the work surface is related to abrasive wear processes, in addition to the associated types of wear, such as:

- oxidative wear – the gradual destruction of the working surfaces of the equipment during friction on the compacted mass, which consists in the formation and removal of oxide layers. The presence of this type of wear confirms its characteristic feature – the smoothness and brilliance of the surfaces. Oxidative wear is enhanced by the intensification of the adsorption and diffusion processes of oxygen through the heating of the friction surface layers. Another powerful factor in the activation of oxidative wear is the plastic deformation of the surface layers of the tool;

- thermal wear – intensive destruction of the surfaces during friction on the compacted mass due to high temperatures heating. As a result of such thermocycling, certain structural transformations occur, internal stresses are forming, which leads to the loss of mechanical strength of the surface layers, appearance of cracks and intense destruction of the surface;

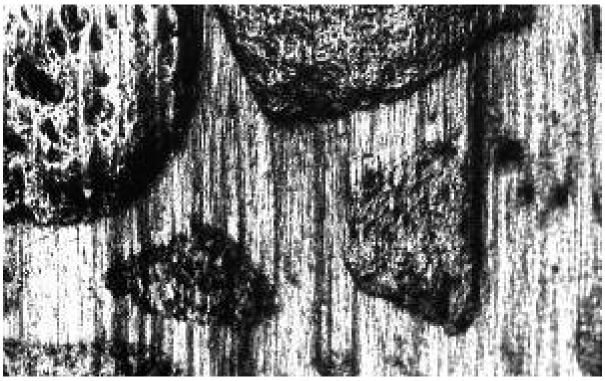
- hydrogen wear – occurs due to the action of hydrogen ions released during the dissociation of various substances and as a result of chemical reactions in which the components of the processing mass participate in the process of frictional interaction [13]. In particular, it was experimentally established that in case of wood processing the composition of the gas atmosphere has the following composition, %: H_2 – 4,2...6, CH_4 – 2, CO – 70...72, CO_2 - 20 [14], in the contact space of the friction pair "wood-steel";

The most common materials for the production of working elements of equipment for processing abrasive-containing masses are high-alloy steels of grades H12M (X12M), R6M5 (P6M5), 12HS (12XC), 9HS (8XC), H18 (X18), as well as cast iron grades CI22 (ЧХ22), CI28 (ЧХ28), CI28N2 (ЧХ28Н2) [15].

One of the effective methods of increasing the wear resistance of the considered equipment is the surfacing of electric arc composite coatings that are resistant to abrasion. The high durability of such coatings is due to the presence in their structure of refractory inclusions, which act as a barrier to the movement of abrasive particles, and also increasing the corrosion resistance of the coating.

In modern conditions, the most widespread are high-chromium surfacing materials based on iron (electrode materials of brands T-590, T-620). Their main disadvantage is the formation of coatings with large-grained structural components of the eutectic type, which do not allow to provide a sufficiently high stability in the conditions of abrasive wear [16].

As an alternative to high-chromium materials, tungsten-containing materials such as “Relit TZ” are used, which are macro-compositional coatings based on tungsten carbides (W_2C, WC) of 0,3 - 1,2 mm in size. However, taking into account the high cost of tungsten initial materials and its growing scarcity, the widespread use of these materials is rapidly losing its profitability.



a

b

Fig. 2. Macro-relief of the wear surfaces while testing the deposited coatings in the abrasive mass (x50):
a – W_2C–WC based coating (“Relit TZ”);
b – TiB_2–TiC based coating

As shown in [16 - 17], it is rational to use titanium compounds (TiB_2, TiC), which are characterized by higher microhardness, and the initial material for their preparation by a substantially lower cost, as an alternative to tungsten compounds in the deposited coatings.

The authors performed comparative tribotechnical tests of W_2C-WC based coatings (“Relit TZ”) and TiB_2–TiC based coatings under the conditions of friction in the abrasive environment [16]. The green 54C F20 silicon carbide was used as an abrasive according to TUU 24.1–00222226–059: 2006 (710 … 1700 μm particle size).

On the basis of the carried researches it was found that the macro-relief of the friction surface of the deposited material "Relit TZ" (Fig. 2, a) is characterized by the presence of small parallel longitudinal scratches formed in the process of interaction with abrasive grains.

On the worn surface, a significant number of substantially sticking out massive inclusions of the reinforcing phase were detected without traces of significant abrasive grain damage. Inclusions of the reinforcing phase act as a barrier to the movement of abrasive particles, and their large size causes the formation of less worn areas of the matrix, located behind the grains of the reinforcing phase. There were not significant damage and deep scratches on the surface of the reinforcing inclusions are observed, which is caused by a comparable level of tungsten carbide hardness (up to 22 GPa).

Macro-relief of the friction surface of a deposited material based on TiB_2 – TiC (Fig. 2, b) is characterized by the presence of small parallel longitudinal scratches. The nature of bond failure indicates the predominance of plastic re-deformation and micro-cutting processes. On the worn surface, a significant number of sticked out bare grains of the reinforcing phase of 20-50 μm in size were found. The microhardness of the reinforcing inclusions of titanium carbides and diborides exceeds the hardness of the abrasive, and is 30 GPa and 35 GPa [18], respectively, which allows to provide a high level of wear resistance under conditions of abrasive action.

The carried studies are confirmed by the results of tests for abrasive wear resistance, highlighted in [16]. In particular, the relative wear resistance of coatings based on TiB_2 – TiC exceeds the serial high chromium coatings by 2,2 ... 3,8 times and is at the level of the wear resistance of coatings based on W_2C – WC. In this case, the total mass content of the main alloying elements in this coating is lower by 2,2 … 2,4 compared with tungsten-containing coatings. Therefore, the proposed tungsten-free TiB_2–TiC coatings can be used as alternatives for high-chromium coatings as well as for the replacement of tungsten coatings (for economic reasons) in the case of large volumes of material.

The practical experience of using tungsten-free coatings on the base of the “Epsilon LTD” intersectoral research and production center during the restoration and strengthening of the working elements of equipment for transporting, mixing and pressing abrasive-containing masses confirms the expediency of their use.

Conclusions

1. The working parameters of modern equipment for transportation, mixing and pressing of abrasive-containing masses are considered. The basic types of wear to which the working surfaces of the specified equipment are exposed during its operation are determined.
2. The list of materials from which the working elements of the equipment for processing abrasive-containing masses are made, as well as the list of the main serial surfacing materials used for strengthening the working elements of the abovementioned equipment, is explained.
3. The mechanism of abrasive wear of coatings based on W_2C–WC and coatings based on TiB_2–TiC was investigated. The results of laboratory tests and practical application substantiate the effectiveness of use of tungsten-free coatings.

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Іванов О.О., Присяжнюк П.М., Луцак Д.Л., Бурда М.Й., Луцак Л.Д. Підвищення зносостійкості робочих органів обладнання для пероблення абразивовмісних мас.

Розглянуто робочі параметри сучасного обладнання для транспортування, змішування і пресування абразивовмісних мас. Визначено основні види зношування, яким піддаються робочі поверхні вказаного обладнання в процесі його експлуатації. Висвітлено перелік матеріалів з яких виготовляються робочі органи розглянутого обладнання, а також перелік основних серійних наплавлювальних матеріалів, що використовуються для їх зміцнення. Досліджено механізм абразивного зношування композиційних покриттів на основі W_2C–WC та покриттів на основі TiB_2–TiC.

Ключові слова: зносостійкі покриття, абразивне зношування, транспортування, змішування, пресування, карбід вольфраму, карбід титану, диборид титану.