On the mechanism of ferromagnetic materials wear reduction

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Abstract

The article proposes a hypothesis on the nature of anti-adhesion processing method by the magnetic field of cutting and deformation tools based on the analysis of operating experience and experimental studies of a wide range of tools. The results of the wear process experimental and mathematical modeling in terms of increasing the magnetic impact are presented. It is found that with the increasing number of impulses, the external magnetic field decreases wear and increases the residual magnetic induction of the samples processed by the magnetic field, and the quantification of changes in the intensity of these processes is showed. A new mechanism of influence is proposed of processing magnetic field on the wear, from which is concluded the appearance of an electronic system with a modified energy level that is resistant to the formation of chemical bonds, causing the adhesion.

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1. Introduction

One of the new physical methods of improving the wear resistance of cutting and deforming tools is processing by the magnetic field (PMF). However, despite the existing effect of the PMF of ferromagnetic materials, the mechanism and factors influencing processing on the wear are still poorly understood. Therefore, the practicability technology of the PMF based on the previously proposed mechanisms [1, 2, 3, 4, 5] does not give a reliable result. This constrains the extended use of this method.

The research conducted by the authors of this article analyzes the operating experience and experimental research on the wear of a large range of instruments based on structural and technological factors. This allows for the

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establishment of [6] the prevailing aspect and causes of wear to cutting tools, to identify causal relationships, and the ratio of total tool wear to the causes for their occurrence. It is revealed that the largest proportion of the cause is the adhesive wear, which may be up to 85%. In practice a significant reduction of tool wear processed by the magnetic field was established (up to 3.5 times). In this regard, the hypothesis about the nature of the anti adhesion effect of this method is given.

The purpose of this work is an experimental and mathematical modeling of the processing of wear in the tribosystem of the tool material - processed material under increasing external magnetic impact.

2. Assessment of influence of the magnetic field on the wear

In the experiments, we used a modernized friction machine such as MI, which provides the testing scheme friction through a "roller-sample". The samples were rectangular prisms of high speed steel R6M5 and alloy steel CVM, hardened by appropriate technologies. A separate roller from steel 45, hardened to a hardness of 44-46 HRC served as the counterbody for each sample. The wear of the samples was evaluated by the weight loss shall be determined by weighing them on laboratory analytical scales. The level of the experimental load for all samples was 300 N.

The samples were exposed to the external magnetic field with of the different the numbers of pulses from 1 to 7, with a pulse duration of 2 seconds caused by setting the tenseness of the magnetic field of 400 kA/m with an adjustable pulse duration. One sample of each steel was not magnetized. They were the control samples.

Diagrams of the dependence of the amount of wear on the samples on the number of pulses of the external magnetic field are presented (Fig. 1). In these graphs, a steady decrease in the amount of wear by increasing the number of pulses of the magnetic effects of the gradual weakening of its influence can be traced, presumably due to the magnetic saturation of the samples' material.

Moreover, for steel CVM multiplicity, the reduction the amount of wear of most of the magnetized sample compared to the control sample was 2.9 - 3.6; R6M5 steel multiplicity of the reduction of the value lies in the range 2.42 - 2.66.

One of the approaches to the assessment of wear is an approach based on the Archard equation wear of resulting from the mathematical modeling of adhesive wear [7].

\[ dW = K_a \frac{q}{H} dA, \]

where \( W \) – is a volumetric wear; \( K_a \) - is a dimensionless coefficient of adhesion; \( q \) – is a contact pressure; \( V \) - is a
sliding velocity; \( H \) – is a hardness of the material; \( A \) – is an area of friction contact.

From the experimental conditions adopted, this equation of wear takes the form [8, 9]

\[
m = K_a \gamma AV \frac{q}{H} t,
\]

where \( \gamma \) – is a density of the material of the wear particles, \( t \) – is a duration of the friction.

The analysis of the equation shows that at constant values of \( \gamma, A, V, q, \) and \( H \) (realized in experiments with the same duration of friction), the value of weight wear is determined only by the coefficient of adhesion \( K_a \).

3. Assessment of influence of magnetic field on the residual magnetic induction

For this reason, we assume that the magnetization gives some new properties to the samples, which influence the adhesive interaction of the modified samples with a counterbody. Consequently, the coefficient of adhesion \( K_a \) in the equation of wear is the most powerful internal factor of wear processing.

In the development of the hypothesis about giving new properties by magnetizing samples, experiments were conducted to determine the dependence of the residual magnetization from the impact of the number of pulses by an external field. For this purpose, 3 samples of steel subjected to magnetization modes with the number of pulses of 3, 6, 9 and 15 with the same duration of exposure to the magnetic field of 2 seconds were examined. The magnetic induction \( B \) of the residual magnetic field at the surface of the magnetized samples was measured by the magnetometer. These surfaces in the following experiments were friction surfaces.

From the measurement results presented in Figure 2 it follows that with increasing the number of pulses of an external magnetic field, the level of residual magnetic induction (and therefore, the tensions of the residual magnetic field) on the friction surface of the samples increased steadily with some weakening at large quantities of pulses.

![Fig. 2. The dependence of residual magnetic induction of friction surfaces of samples from the number of pulses of external magnetic field](image)

(1 – is a sample from steel R6M5; 2 – is a sample from steel CVM; \( n = 0 \) – without PMF)

4. Assessment of the influence of residual magnetic induction by an amount of wear

From a comparison of the experimental dependences of wear (Figure 1) and the residual magnetic induction (Figure 2) from the number of pulses \( n \), it can be seen that while in the process of pumping the samples’ material by the energy of the magnetic field, two processes take place simultaneously the residual magnetic induction increases and decrease the wear decreases amount.

We think that the growth process of the residual magnetic induction in the interaction of the friction surfaces leads and initiates the reduction rate of wear. In this case, the degree of conditionality of the second process
(reducing the rate of wear), by the first (increasing residual magnetic induction) is important.

The computer processing of the experimental results allowed both processes to be represented as functions of the same variable, rather accurately reproducing the experimental dependence (divergence less than 10%).

\[ B = An^{0.35}, \]
\[ m = Cn^{-0.67}, \]

where \( A, C \) – are the constant coefficients.

Comparison of functions (3) and (4) in the exponent of the variable values (differing by almost 2 times) shows a lack of full conditionality of reducing the rate of wear by the process of increasing residual magnetic induction. It can be seen that in the process of pumping the samples by the magnetic energy, the rate of reducing wear exceeds the growth rate of the residual magnetic induction.

A quantitative estimate of the difference in the rates of passage of both processes as a function of the number of pulses of the magnetization can be done by comparing the absolute values of the current intensities changes of the residual magnetic induction \( J_1 \) and reducing the rate of wear \( J_2 \) of the processes considered, presented in the form

\[ J_1 = \frac{\Delta B}{\Delta n}, \quad J_2 = \frac{\Delta m}{\Delta n}. \]

where \( \Delta B, \Delta m, \Delta n \) - are the absolute values of the current changes of the magnetic induction and the wear amount at the corresponding value of change of the number of pulses.

The results of comparing \( J_1 \) and \( J_2 \), shown in Fig. 3, illustrate that the intensity of wear reduction is more than the intensity of increasing the residual magnetic induction throughout the range of increasing the number of pulses. The intensity reduction of wear is always higher than the intensity of accumulation of magnetic induction by 1.5-2 times (Fig. 4).

![Fig. 3. Changes in the current intensities of wear reduction and increases in magnetic induction.](image1)

![Fig. 4. The ratio of current intensities of wear reduction and increases in magnetic induction.](image2)
5. Discussion of the research results

From the above, it follows that the material of the pump energy to the wear process affects not only the magnetization factor, but also affects additional factor which is anti-adhesive in nature and in its manifestation also expends the part of the pumped energy. Moreover, the accumulation of magnetic induction in the material is a contributing and necessary process.

Thus, in principle it is possible to use the following mechanism of influence PMF on the wear. The external magnetic field in the ferromagnetic material orients the domains in a direction that create magnetization of the solid material. In accordance with the theory of quantum-mechanical structure of the atom, the external magnetic field changes the energy state of the molecular orbitals of the interacting crystal lattices. When the magnetic field is removed, the residual magnetization, together with part of the energy of the friction phenomena, supports energy changes. This electronic system is more resistant to the formation of chemical bonds, causing the adhesion. Reduced activity of adhesion processes helps reduce the amount of wear.

The proposed mechanism corresponds to the quantitative assessment (85%) of causes of tool wear in practice and on this basis a hypothesis is put forward about the anti-adhesive nature of the influence of the magnetic impact on the wear resistance of tools.

Conclusion

- The studied steels are predisposed to increased wear resistance by the using the PMF, and the multiplicity of reducing wear amounted for steel CVM from 2.9 to 3.6, for steel R6M5 - from 2.42 to 2.66.
- It has been established experimentally that in reducing the wear, the anti-adhesive factor plays a leading role and the role of the magnetization is secondary.
- A new mechanism of reducing wear as a result of PMF was proposed and one of the leading factors of influence was found to be the number of pulses of the magnetic field. The optimal values for impact (6 ... 7) were installed.

References