

Multidisciplinary Investigations Regarding the Wear of Machine Tools Operating Into the Soil

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Abstract: The paper presents the results obtained by the authors in investigating the problem of wear of work organs of machines working in continuous interaction with the soil. The phenomenon of the interaction of the tools of agricultural machinery for ploughing, and the soil, is a complex of phenomena, one of the most difficult to model. Among the phenomena involved in this interaction, friction and wear (of many types) are the most important. We did not take into account the chemical wear, and by the wear caused by weather conditions. Research has focused on formulating a theory that has more than a descriptive character, for it be used for application purposes. For this we used classical theoretical models, mathematical models based on the theory of continuous bodies, theory of flow of fluids around the profiles, as well as other theories, approached or not, in an attempt to solve as satisfactorily the issue of the wear, for the tools of the agricultural machines for the tillage. We also sought to highlight the fact that wear is a phenomenon on a micro and macro-scale scale, and its generating causes must ultimately be related to observable effects, on the macro-structural scale.

Keywords: wear, friction, soil, tillage

1. Introduction

The physical phenomenon called wear is a very complex phenomenon, therefore difficult to define. In fact, a definition in a strict sense is impossible to give for any notion, because sooner or later it leads to a vicious circle. However, we accept definitions as many words that intuitively suggest the range of phenomena we refer to. For example, in [1], [2], [3], [4], wear is associated with notions: damage, eroding, scrape, scratch, friction, fret, wear. An engineering definition of the wear phenomenon we find in [5]: "Removal of material due to mechanical process under conditions of sliding, rolling, or repeated impact. Included are abrasive wear, fatigue wear and adhesive wear, but not the corrosive and thermal wear." In [8], wear is defined as the detachment of superficial layers of a solid body due to mechanical actions (friction, erosion, etc.) or chemical (oxidative corrosion, etc.) or to both kinds of actions.



There is no need to emphasize once again the special importance of studying the phenomenon of material wear. We limit ourselves to making some clarifications relative to the limited scope that we are referring to in this article. For agricultural machines for soil works, the wear of work organs is of particular importance. First of all, they must be designed to meet agro-technical requirements, but at the same time to reduce friction with soil and, implicitly, wear of organs. Secondly, the user of such a machine has to control the process parameters, having among the main objectives to reduce or maintain the value as close as possible to the minimum, for the forward-pull force. The draft (whose growth also involves increasing energy consumption and eventual qualitative losses in soil processing) depends heavily on the width of the attack board of the tools, and on the settlement angle of the work organ, [6]. All the investigations that we will make next, relate to a chisel plow or scarifiers. A typical example is drawn in figure 1.

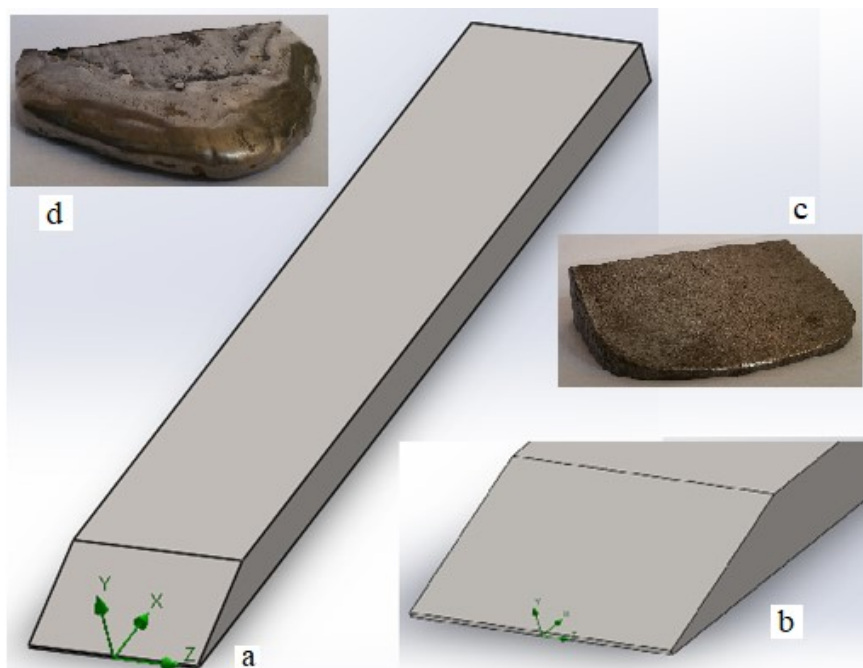


Figure 1. Typical tools for chisel plow or scarifier: geometrical model (a, b), new chisel head (c), chisel head worn and loaded by welding.

Obviously, in order to estimate wear, we need to quantify this magnitude. According to [8], the wear intensity is expressed by the ratio between a parameter that characterizes the wear (e.g. the weight of the loose layer) and a parameter that characterizes the conditions in which the wear was produced.

Models and methods for approach with the wear problem of agricultural machinery used for soil tillage

The five subchapters of this chapter are all theoretical or theoretical-empirical methods involved in solving the problem of the wear of the tools of the agricultural machinery for soil tillage. Not all of them lead to a final estimate of wear, some of them just help others methods to get some information. This information is then used to develop the final wear estimation formula.

1.1 Wear of tools of agricultural machinery for soil tillage

The tools of agricultural machinery for soil tillage are: plow mouldboards, shares and knives, chisels, arrows and other types of tillage tools. These tools are made up of a solid body in the category of knives, caught on the supports of the tools. These work bodies wear out by friction with soil particles and with the harsh components of the soil.

The main wear of the chisel body is manifested on the blade, especially at the top. The top of the blade evolves from a width of between 0.5 and 1 mm (at the fabrication, see figure 1, c), [9] up to a width of 2-3 mm or more, (see figure 1, d) until it is diagnosed as worn and is sharpened or replaced. Accordingly, the mass of the removed material increases. A more complex measure of wear is obtained by dividing the mass of the loss material to a product of sizes involved in describing the aggressiveness of the phenomenon: the length of the road travelled, the aggressiveness of the soil, the working speed, etc. In [9] it is also specified for such work organs, besides the condition on the width of the blade, the condition of not having cracks (especially in the blade top area). It is known that cracks are the causes of local or global damage, favouring rapid organ wear.

The users of agricultural machines equipped with tools of this type have a fairly simple way to estimate wear. They can be based on measuring the traction force in a standard polygon, where the plow was also tested on the first use of the work organs. A wear criterion is, for example, that a set of tools is considered to be worn when it increases by more than a certain percentage the resistance force opposite the tractor. The test can be done for the entire machine or separately for each work piece.

1.2 A list of parameters that characterize the wear phenomenon

In this paper, the wear phenomenon intervenes only through the action of the soil on the tools. So the wear is produced by rubbing a solid (work organ) with a material that can be considered solid, or, if necessary, another type of material (a special fluid, as will be seen in the following chapters). In these circumstances, among the main parameters that are considered for investigating this phenomenon, we considered:

Table 1. List of parameters involved in the wear process.

Parameter	Notation	Unit
The roughness of the metal surface of the tools	R_a, R_t	μm
The hardness of the tools	Br	
The yield strength of the tools material	σ_Y	Pa
Ultimate tensile strength of the tools material	σ_R	Pa
Fatigue strength of the tools material	σ_{Nf}	Pa
Shear strength of the tools material	τ_Y	Pa
Ultimate shear strength of the tools material	τ_R	Pa
Density of the tools material	ρ_w	$\text{Kg}\cdot\text{m}^{-3}$
Tools width	b	m
The width of the cutting edge of the workpiece	h	m
Working depth	a	m
Settlement angle	α	degree
Soil density	ρ_s	$\text{Kg}\cdot\text{m}^{-3}$
Working speed	v	$\text{m}\cdot\text{s}^{-1}$
The working width of the tillage machine	B	m

1.3 Wear and erosion phenomenon

Among the words that appear in the definition of notion of wear are erosion. This mutual positioning of the two notions is not accidental. It refers to the phenomenon of erosion of the slopes under the action of rain.

In order to open a new investigation path, it is enough to recall Wischmeier's formula [7] for estimating pluvial erosion. This equation is called Universal Soil Loss Equation and have the next form:

$$A = RKLSCP \quad (1)$$

where A the long-term average annual soil loss, R is the rainfall erosivity, K is the soil erodibility, L and S are topographic factors and C and P are cropping management factors.

By similarity we could replace formula (1) with formula (2):

$$U = R_s K_o L_o S_o C_o P_o \quad (2)$$

where U is a measure of wear, R_s is a measure of soil abrasion, K_o is a measure of the vulnerability to wear of the tools material, L_o and S_o are factors that represent the influence of the tools geometry, C_o and P_o may be factors indicating the processing, possibly initial treatments of the body.

1.4 Simulation of wear of the tools using structural models

Structural patterns of material wear phenomena have been used for some time. You can imagine in immense amount the structural models of the wear phenomenon. The selection of these is made by the extent to which they are applicative and not merely descriptive. This means that it is possible to simulate a phenomenon with the help of the structural model, in order to achieve concrete goals: behaviour prediction in difficult experimental conditions or optimal calculus. We used structural models to simulate the interaction between the tools of tillage machines and the soil. In all the elaborated structural models, the tools were modelled as a linear-elastic or rigid material. The soil, however, to be consistent with the most elemental experimental findings, should be considered as a material, at least elastic-plastic, even viscous-elastic-plastic. We have created a structural model in which we assumed the soil as a high density fluid, and the tools, is a rigid body around which the fluid that simulate the soil moves.

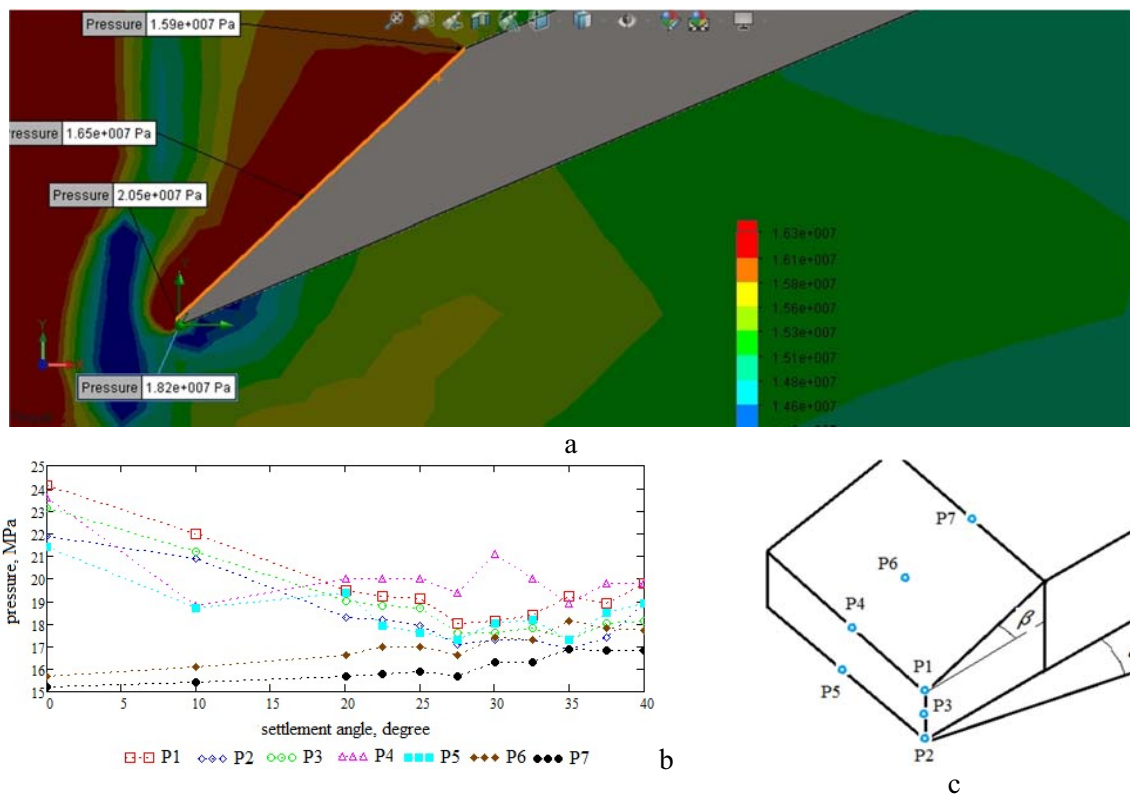


Figure 2. Structural model of motion of the tools in the soil modelled as rigid solid in the high density current flow and constant speed (2,7 m / s).

From the point of view of wear theory, the structural models are used to extract some necessary information for other mathematical models of the same phenomenon. The structural model in which soil is modelled as a fluid material is used to estimate soil pressures on the tools. This information is then used to model the reducing of the degree of roughness of the surface of these work organs, especially in the neighbourhood of edges and thin surfaces. The structural model in which the soil is considered to be a solid material, based on information from the fluid soil model (Figure 2, a), attempts to estimate what characteristic dimensions have those formations called "peaks" that can be irreversibly deformed or broken by pressure loads determined on the surface of the tools using the model with the soil modelled as fluid.

From the structural model in which the soil is modelled as a fluid, we take the pressure in the neighbourhood of the cutting edge of tools, assuming that the hydrostatic soil pressure as the fluid is given by the modulus of the soil elasticity, and the dynamic pressure is given by the product of the fluid density and the square of the movement speed of the organ or fluid. The pressure variation in seven points on the tools, according to the angle of settlement is shown in Figure 2, b. The location of the seven points on the tools is given in Figure 2, c. The pressure values so found are used to estimate the gauge of the metallic formations that can be irreversibly broken or deformed by the action of pressure. So, it is also possible to approximate the intensity of the action of the abrasive bodies, which continues the wear beyond the appreciable reduction in roughness.

1.5 Roughness as a measure of wear

The initial roughness of a tools of a tillage machine is characterized by a series of statistical sizes. The roughness of the work surface changes according to the length of the trajectory travelled, the working speed and the aggressiveness of the soil (properly characterized). The acceptable wear limit in this particular case is related to the cutting edge of the tools, but also to the length of the inclined plane in the cutting area, measured along the organ.

In manufacturing, a roughness class is not required for the work organ. Through rapid wear, the tools reaches small values of the roughness class. For the wear of the tools of the agricultural machines for soil tillage, it is possible to use the roughness, drawing a curve that has as abscissa a measure of the performed work (e.g. the number of hectares worked), and on the ordinate, the average value of the roughness, in several points, or fixed measurement areas. It can be considered that the chisel body has, initially, the roughness class (Roughness ISO, [10]) N12 ($R_a = 50 \mu\text{m}$, $R_r = 200 \mu\text{m}$). For work organs studied in operation, on roughly 310 hectares worked in hard and sandy soil, the roughness reached class N6 ($R_a = 0.8 \mu\text{m}$, $R_r = 4 \mu\text{m}$). The shortening in length of the tools was approximately 70 mm (from 300 to 230 mm). Starting from these experimental findings, elementary calculations and simple considerations lead to the following form of wear dependence, R_a , on the worked surface, S :

$$R_a(S) = R_a^0 \exp\left(-\frac{S}{S_1} \ln \frac{R_a^1}{R_a^0}\right) \quad (3)$$

where R_a^0 the initial roughness characteristic, and S_1 is the area for which the measured roughness indicates the value R_a^1 . The wear function expressed in the roughness variation of the working surface can be expressed also in the mass of the current or lost material, using the density of the material and the geometric approximation of the material portion at the top of the organ that is lost by eroding (estimation is made only for the top of the tools). In the Figure 3 shows variations in the roughness and mass of the body as well as the mass of material lost through wear, depending on the worked surface.

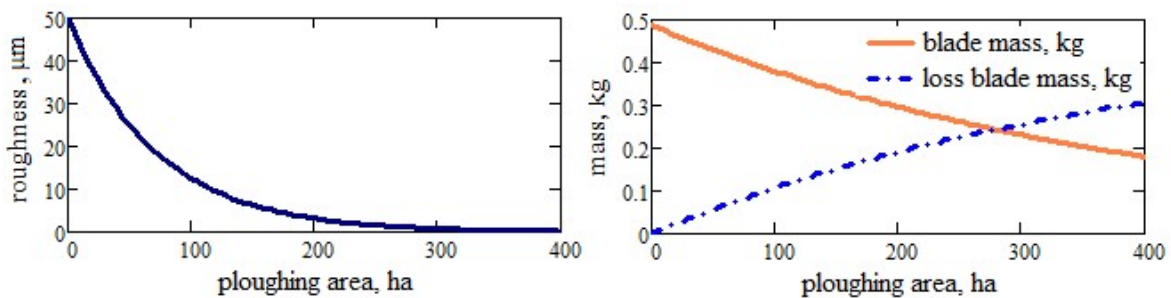


Figure 3. Graphical representations of the wear of the tools in roughness and themass (actual and lost), depending on the number of hectares worked.

If we annotate with s the length of the trajectory travelled by each tools, for surface processing S , we can accept the approximation:

$$s = \frac{S}{B} \quad (4)$$

then the roughness and mass functions of a tools can be written using as argument the length of the trajectory travelled:

$$R_a(s) = R_a^0 \exp\left(-\frac{s}{s_1} \ln \frac{R_a^1}{R_a^0}\right) \quad (5)$$

and similar formula for current and lost weight.

The distance travelled by the machine and implicitly by the tools may be related to the mechanical work necessary to overcome the resistance to soil deformation and thereby the soil characteristics and the working speed. In this way can be obtained, also other interesting relationship for wear. To increase

the accuracy of the empirical formula (1), we recommend as many experimental measurements as possible and the estimating the coefficients of this function by the least squares method. Also, on either the formula (1) or the more complicated forms, a dimensional analysis of the wear phenomenon (in the set of parameters in Table 1) is recommended. This analysis can lead to the determination of dimensional combinations with which new wear approximation functions can be formed.

2. Results

The results presented in this paper are included in the second part. Synthetically, these are:

- practical wear criteria for tools of tillage machinery,
- a list of parameters involved in various mathematical models of the surface wear process,
- the alternative of surface wear modelling using a pattern similar to the USLE model of slope erosion due to precipitation,
- information and explanations about the possibilities of using structural models in the partial or total description of the wear phenomenon,
- a description of the surface wear of tools of tillage machines, based on the variation of roughness and the connection with the formulation in terms of variation of the mass of the object subjected to wear.

3. Conclusions

In view of the results presented and the broad description, some important conclusions can be drawn for the continuation of the investigations and for the orientation, possibly preferential, to some of the directions described in the second chapter.

A first important conclusion is that the phenomenon of wear of surfaces (metallic or not) is a complex phenomenon, with factors of influence on both the micro scale and the macro scale. Moreover, the implication of statistical features is obvious. Even describing the surfaces in terms of roughness is a statistical one. Also the action of some of the factors that produce wear, has random character.

As a result of the first conclusion, an approach of the wear problem, using the methods of statistical physics, would be necessary. However, such an approach is very difficult and does not guarantee the solution of the practical problems of the wear phenomenon.

The results from subchapter 2.1 and 2.5 show that there are enough practical resources to formulate some phenomenological criteria (in terms of macrostructure) of wear. These criteria are used in practical applications. Many of these can be mathematically modelled after a reasonable amount of experiences. Subchapter 2.5 proves this statement.

The table with the factors involved in the surface wear process, from subchapter 2.2, shows that there are many parameters whose influence in this process is still waiting for a profound assessment. Generally, this investigation involves a great deal of experience. These are often very expensive. For this reason, we appreciate that important results in this direction will come at a slow pace.

The alternative to surface wear modelling through a formula of the type used in the classical theory of slope erosion due to rainfall is tempting. However, before performing ample experimental activity, it is necessary to give a complete definition to the variables involved in the equation (2).

The use of structural models in the surface wear study is useful for verifying hypotheses or for estimating the effects of some parameters in the process. However, the prospects of using these models are related to their experimental validation. Experimental validation is costly and this involves checking not only the results of these models but, to the extent possible, verifying working hypotheses. Finally, in Chapter 2.5 we have shown that the roughness of the tools surface can give a measure of the wear, especially if it is supplemented with the variation in the length of the organ or the variation of the geometry of the cutting edge.

In essence, it can be said that applications that aim at optimizing or improving the wear process are only possible through a very extensive experimental activity. Even if we try to optimize some aspects of the wear problem by theoretical procedures, the models used need experimental validation.

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References

1. https://www.google.ro/?gws_rd=cr&ei=ysplWeX1LonA6QTchKG4Cg#q=wear+definition
2. Merriam –Webster Dictionary, <https://www.merriam-webster.com/dictionary/wear>
3. Cambridge Dictionary, <http://dictionary.cambridge.org/dictionary/english/wear#translations>
4. <https://en.wikipedia.org/wiki/Wear>
5. http://www.engineering-dictionary.org/MECHANICAL_WEAR
6. E.Y.H Bobobee, G. Gebresenbet, Effect of cutting edge thickness and state of wear of ploughshare on drought force and heart rates of Sanga oxen in Ghana, Soil & Tillage Research 95 (2007), 298-307, ELSEVIER.
7. W. H. Wischmeier, D.D. Smith, Predicting Rainfall-Erosion Losses from Cropland East of the Rocky Mountains, Guide for Selection of Practices for Soil and Water Conservation, Agricultural handbook, no. 282, 1965.
8. C. Iacob, S.I. Gheorghita, M. Soare, L. Dragos, Dictionar de mecanica, Editurastiintificasienciclopedica, Bucuresti, 1980.
9. V. Scripnic, P. Babiciu, Masiniagricole, Editura CERES, Bucuresti 1979.
10. https://en.wikipedia.org/wiki/Surface_roughness