THE UNIVERSITY POLITEHNICA OF BUCHAREST

FACULTY OF MECHANICAL ENGINEERING AND MECHATRONICS DOCTORAL SCHOOL

DEPARTMENT OF MACHINE ORGANS AND TRIBOLOGY

THESIS SUMMARY

CONTRIBUŢII PRIVIND STUDIUL PROCESELOR DE UZARE ÎN MEDII ABRAZIVE, CU APLICAŢII LA ORGANELE DE LUCRU ALE MAŞINILOR AGRICOLE
/
CONTRIBUTIONS REGARDING THE STUDY OF WEAR PROCESSES IN ABRASIVE ENVIRONMENTS, WITH APPLICATIONS TO THE WORKING BODIES OF AGRICULTURAL MACHINERY

Author: Laurențiu-Constantin VLĂDUȚOIU

Scientific Leader: Prof. Phd. Andrei TUDOR

București, 2022

CONTENT

KEY WORDS: Working bodies; intensive wear processes, abrasive media, chisel-type knives; coefficient of friction; cohesion strength; adhesive wear; elastic deformation; abrasive wear; penetration process.

THESIS ABSTRACT
INTRODUCTION

The doctoral thesis entitled CONTRIBUTIONS REGARDING THE STUDY OF WEAR PROCESSES IN ABRASIVE ENVIRONMENTS, WITH APPLICATIONS TO THE WORKING BODIES OF AGRICULTURAL MACHINES was developed within the Faculty of Mechanical and Mechatronics Engineering, Doctoral School, Department of Machine Bodies and Tribology and contains original contributions in the processes of wear in abrasive environments, with applications to the working organs of agricultural machines. The thesis is part of the concerns of the Machines and Tribology collective to determine the coefficient of friction between the knife and sand and to determine the cohesive strength of dry and wet sand with the chisel-type knife to work the soil. The first part of the thesis (chapters 1-3) presents the literature data regarding the current state of knowledge in the field of wear processes in abrasive environments, with applications to the working organs of agricultural machines.

Chapter 1, entitled MECHANICAL CHARACTERISTICS OF SOILS SUBJECT TO WORKING WITH AGRICULTURAL MACHINES includes a bibliographic study on the physical properties and mechanical characteristics of the soil, with the influence on the working organs of agricultural machines, and a bibliographic study of the penetration resistance of soils and usable devices (*Visa I. , and others, 2009; Dokucheaev, 1983*).

Chapter 2 entitled THE CURRENT STAGE OF RESEARCH REGARDING THE WEAR OF THE ACTIVE ORGANS OF AGRICULTURAL MACHINES presents a study of the resistance to abrasive and adhesive wear of the materials and a synthesis regarding the definition of the organs of agricultural machines with intensive wear processes and with removal from operation as a result of excessive wear (*Braharu D. and others 2007; Tanco C., 2011; Ţenu I. and others 2009; Tomescu, D., 1975*).

Chapter 3 entitled STANDS, DEVICES, EQUIPMENT AND EXPERIMENTAL METHODOLOGIES USED UP TO THE PRESENT IN RESEARCH FOR DETERMINING THE WEAR OF ACTIVE ORGANS OF AGRICULTURAL MACHINES presents the analysis of the effects of hardening the surfaces of the plow coulters for plowing on the wear of the coulters, for the experiments done before the thesis, at INMA (*Visa I. , and others, 2009; Matache M. and others, 2006; Epure I. C., 2011*).

The second part of the thesis, (chapters 4-5), presents the original contributions made by the thesis.

Chapter 4 EXPERIMENTAL RESULTS REGARDING CHISEL KNIFE PENETRATION AND WEAR describes the particular aspects regarding the experiments carried out: the equipment used and the work methodology used to carry out the experiments.

Chapter 5 entitled THEORETICAL WEAR MODELS OF KNIVES OF SOIL TILLERS also presents the ingenious adaptation of an adhesion wear model to the particular knife-soil case and the use of dimensionless parameters as a similarity criterion (*Cardei P., 2008*). It presents the realization of a new model of abrasive wear of the knives of soil tillage machines with abrasive particles fixed in the matrix and within this program, 3 calculation programs were made in the MATCHAD 14 utility regarding wear by adhesion, wear by abrasion and forces and stresses in the penetration process.

Part III of the thesis includes the conclusions of the doctoral work. The general conclusions of the paper and the possibilities for further development are presented at the end of the paper, along with the author's original contributions.

The thesis ends with a Bibliography chapter and with the annexation of work published in extenso.

ORIGINAL CONTRIBUTIONS

CHAPTER 4

EXPERIMENTAL RESULTS REGARDING THE PENETRATION AND WEAR OF THE CHISEL TYPE KNIFE

4.1. TEST CONDITIONS

Fine quartz sand for dry adhesive mortars for commercial application, obtained by washing and mechanical grading, was chosen as the test medium. According to the Attenberg scale, this sand falls into the granulometric class fine sand and coarse sand with a particle diameter between 0 and 0.3 mm.

To determine the granulometry of the material in which the experiments were carried out, a vertical sieving system was used - vibrator RETSCH - AS - 200 beisec, equipped with timer and amplitude variator.

A brand precision scale was also used to determine the weight of the chisel knives KERN EG.

The tests were carried out under different working conditions, with dry sand and wet sand.

The moisture content of the sand in which the samples were made was determined using a Theta Probe sensor type ML2x

4.2 EXPERIMENTAL TESTS ON THE DETERMINATION OF THE WEAR OF CHISEL KNIVES MADE OF DIFFERENT TYPES OF MATERIALS TESTED IN DRY SANDY SOILS

The experimental test stand for chisel-type knives from U.T. Cluj-Napoca

In the first phase, a test stand made entirely by the Mechanical University of Cluj-Napoca was used (*Fechete L.V., 2008*).

For experiments, a chisel-type support and 3 chisel-type knives were made from different materials C 45 (1), C 45 heat-treated by tempering (2), E 295 (3).

The chisel-type knives were mounted in a row in the test stand, where they worked at a depth of 22 cm, so that their wear could be determined after a number of hours of operation.

These chisel knives were weighed before being mounted on the test stand, where they were left to run for an hour, after which they were weighed and mounted back on the stand for another hour of testing (*Vlăduțoiu L . 2021*). The procedure was repeated 7 times for each knife, thus tracking material losses due to wear (table 4.1).

Table 4.1 - ***Centralizer of data obtained for chisel-type knives subjected to wear analysis***

Time [h]	**Chisel type knife C 45 (1)**		**Chisel knife C 45 heat treated by hardening (2)**		**Chisel knife E295 (3)**	
	Initial weight [g]	***Mass difference (effective wear) [g]***	***Initial weight [g]***	***Mass difference (effective wear) [g]***	***Initial weight [g]***	***Mass difference (effective wear) [g]***
0	259.52	0	257	0	238.16	0
1 h	259.1	0.42	256.47	0.53	237.89	0.27
2 h	258.77	0.33	256.18	0.29	237.65	0.24
3 h	258.43	0.34	255.99	0.19	237.44	0.21
4 h	258.12	0.31	255.78	0.21	237.3	0.14
5 h	257.78	0.34	255.6	0.18	237.18	0.12
6 h	257.52	0.26	255.44	0.16	237.02	0.16
7 h	257.27	0.25	255.3	0.14	236.84	0.18
Total uzură		**2,25**		**1,7**		**1,32**

The experimental test stand for chisel-type knives from INMA Bucharest

In the second phase, a test stand made by INMA Bucharest, similar to the one at the Mechanical University of Cluj, was used.

With the help of this stand, different types of tiller knives can be tested in laboratory conditions, by changing their functional parameters: working depth, the angle of the tiller knives, the working speed (established indirectly as the tangential speed in the circular movement of the support arms), the granulation and the humidity of the test environment.

For the tests, 3 types of chisel type knives were made from different types of materials: C 45 (1), C 45 heat treated by tempering (2), E 295 (3), and for each type of chisel knife there were made 3 knives (*Vlăduţoiu L, 2020*).

The chisel-type knives were mounted in a row in the test stand, where they worked at an angle of attack of 27° and at a depth of 22 cm, so that their wear could be determined after a number of hours of operation, in figure 4.1, for our data, choosing a polynomial distribution.

Also, the evolution of the increase in the degree of wear of the 3 chisel-type knives during the 8 hours of operation is represented. Thus it can be observed that the E295 chisel-type knife suffered less wear throughout the period of operation, followed by the heat-treated C 45 chisel-type knife, and the C 45 chisel-type knife suffered the greatest wear.

It can also be observed that the chisel-type knives suffered the highest degree of wear during the first hours of operation, after which the degree of wear decreases.

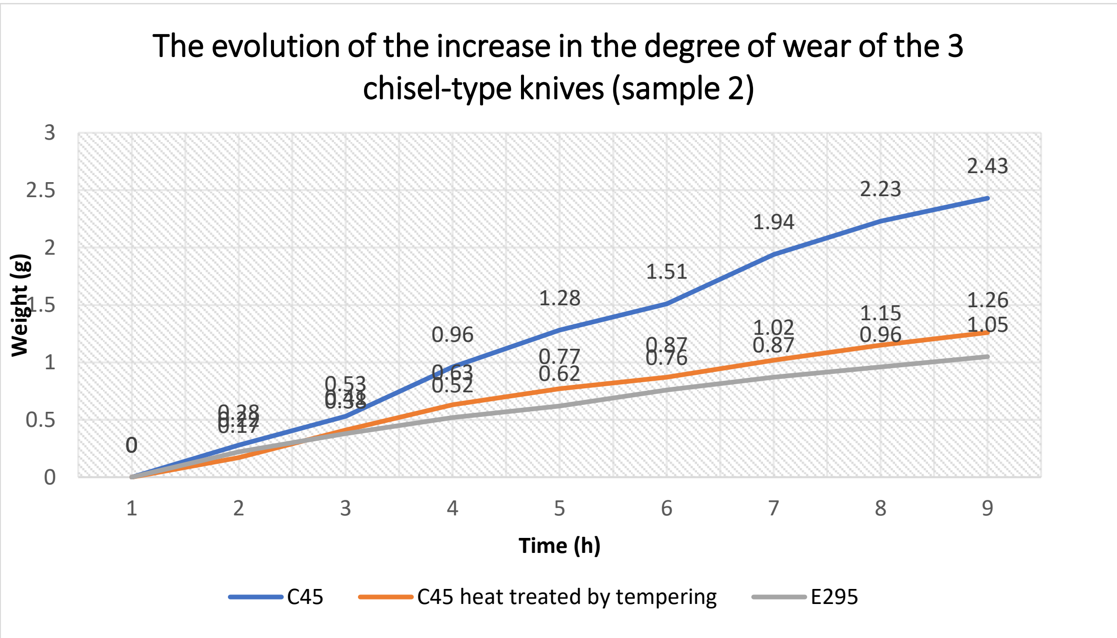


Figure 4.1. - ***The evolution of the increase in the degree of wear of the 3 chisel-type knives in dry sand***

During the 8 hours of operation in wet sand (figure 4.2), the E 295 chisel-type knife suffered 9.54 grams of wear, the heat-treated C 45 suffered 12.55 grams of wear, and the C-chisel-type knife 45 a wear of 14.3 grams.

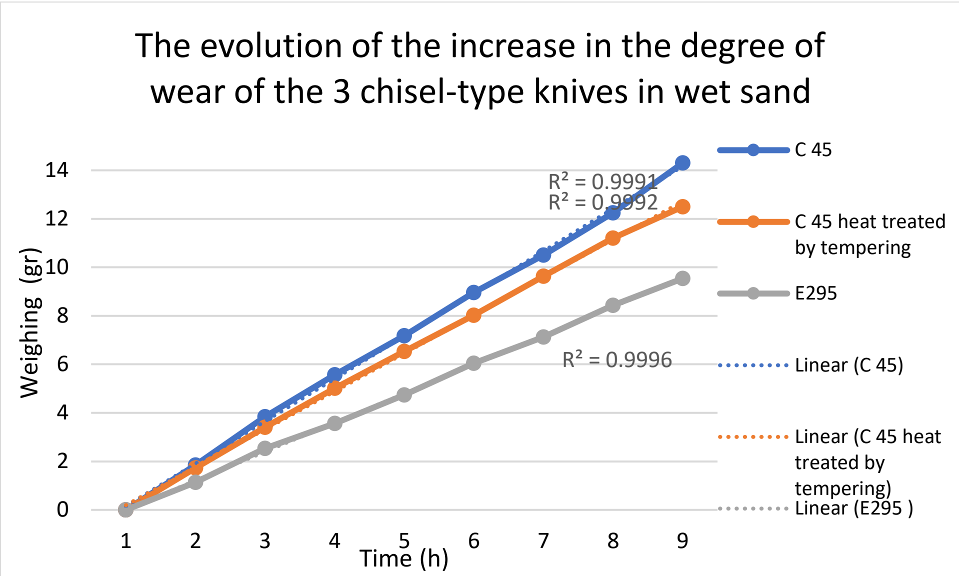


*Figure 4.2. - **The evolution of the increase in the degree of wear of the 3 chisel-type knives in wet sand***

CETR universal tribometer experimental stand (Campbell, CA, USA)

These experiments were carried out with the help of the CETR universal tribometer, in the equipment of the Department of Machine Parts and Tribology, UPB Bucharest. This device can monitor and/or control the force on 2 axes and the movement on three axes, thus in this case both the loading force, the displacements and the speed of the indenter could be accurately measured.

In figure 4.3 and 4.4 we have the average of the penetration tests of the chisel-type knife in the condition of dry sand and wet sand where it can be seen that the highest maximum force is T_6 = 3,5 N for wet sand and the lowest force, we have at T_5 = 0,5 N for dry sand.

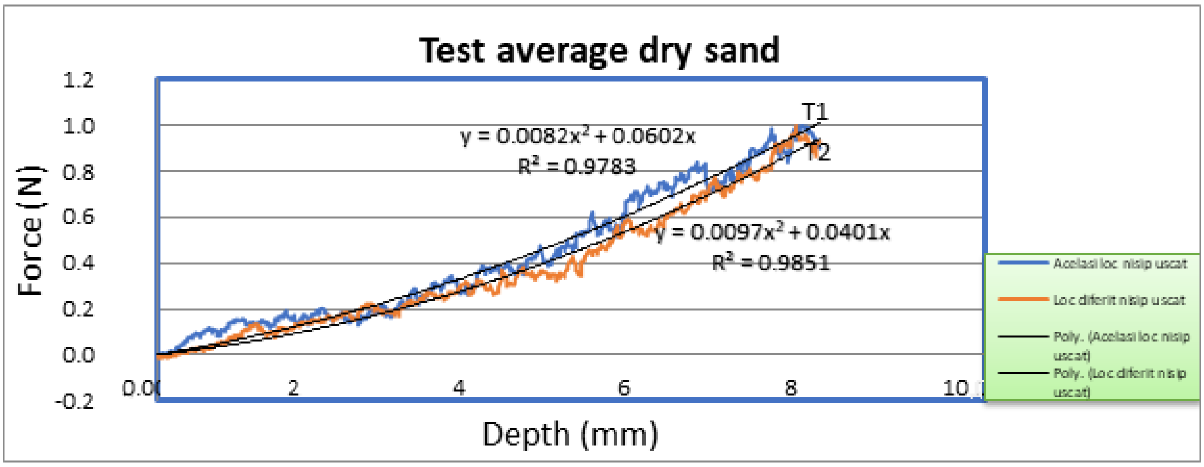


*Figure 4.3. - **The experimental curves resulting from the tests performed with the chisel type knife in dry and wet sand conditions in the same place** (T_6 - wet sand; T_5 - dry sand)*

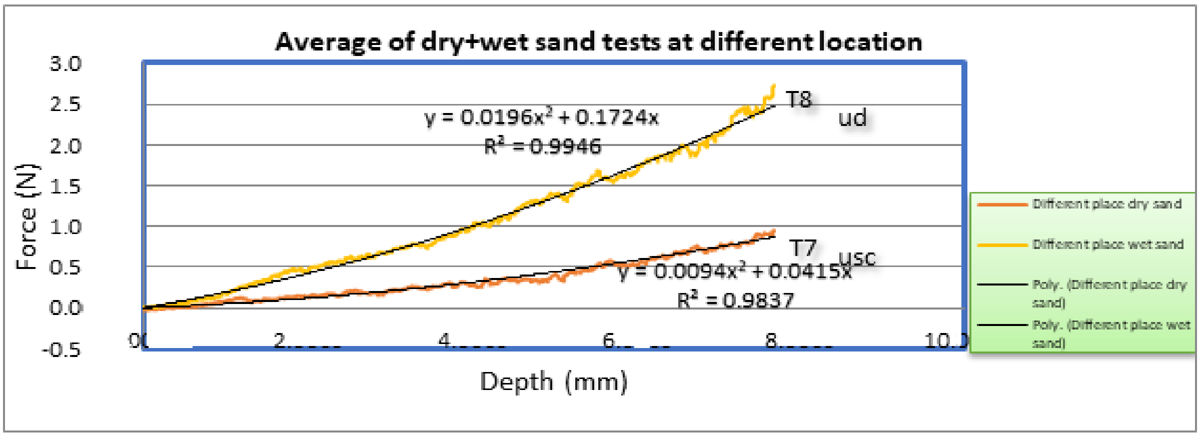


*Figure 4.4. - **The experimental curves resulting from the tests performed with the chisel type knife in dry and wet sand conditions in different places** (T_7 dry sand; T_8 - wet sand)*

From the analysis of the experimental curves regarding the dependence of the penetration force on the depth, it can be seen that the presence of water in the sand (wet sand) leads to a significant increase in the forces both when the penetration occurs in the same place and in different places.

CHAPTER 5. THEORETICAL MODELS OF THE WEAR OF KNIVES OF SOIL WORKING MACHINES

The economic implications of the effects of wear processes and the development of knowledge in the fields of contact mechanics, metal chemistry, rheology, tribology, etc. have determined the phenomenological approach to the detachment of wear particles for different materials operating in dry or lubricated environments. The wear equations are the "tools" for analyzing the behavior of materials in different work areas and which have relative speed.

Meng and Ludema identified about 200 "wear equations" for different materials and working conditions (*Meng, 1995*). The wear equations take into account the forms of surface damage and include the following parameters: normal force, relative sliding speed or rolling speed, contact surface geometry (local and macroscopic), working environment (air, lubricant, vacuum, etc.) and the properties of the materials involved (thermal, mechanical and chemical).

The initial wear equation is known as the Archard or Rabinowicz equation:

$$v_{uz} = k_{uz} \cdot \frac{F_n \cdot s}{H} \tag{5.1}$$

Where: v_{uz} – is the volume of material worn and removed from the surface;

F_n – normal force;

s - sliding distance;

H – the hardness of the material;

k_{uz} – dimensionless coefficient of wear.

Model of adhesive wear of the knife used in machining machines matchad program model of sharpened chisel use

Mechanical behavior of soil

One of the main characteristics of soil is that shear strains increase progressively as shear stresses increase and at a certain strain value damage to bonds within the material occurs. The soil cannot take tensile stresses.

According to the Coulomb model, the critical shear strain of soil (τ_f) is

$$\tau_f = c_{oz} + \sigma \cdot \tan(\phi) \qquad (5.2.1)$$

c_{oz} - is the cohesive strength of the soil material particles;

σ - is the normal (effective) stress in the considered plane;

ϕ - is the angle of internal friction in the soil (natural slope angle).

he state of stress leading to damage is analyzed with Mohr's circle. Shearing begins at maximum stress and occurs in the plane that makes the angle (π/4 -ϕ/2) with the principal direction of maximum stress.

The Mohr-Coulomb damage criterion relates the stresses at a point to specific parameters ϕ and coz. Two cases are distinguished:

1) The earth acts on a fixed vertical wall (active earth pressure)

2) A vertical wall "pushes" the earth (passive earth pressure)

$$\sigma_{3p} = \sigma_{1p} \cdot \frac{1 - \sin(\phi)}{1 + \sin(\phi)} - 2c_{oz} \cdot \frac{\cos(\phi)}{1 + \sin(\phi)}$$

Whwrw σ_{3p} și σ_{1p} are the principal effective stresses (without the effect of pore water)

or $\quad \sigma_{1p} = \sigma_{3p} \cdot \frac{1+\sin(\phi)}{1-\sin(\phi)} + 2c_{oz} \cdot \frac{\cos(\phi)}{1-\sin(\phi)}$

It is noted $\quad k_{a(\phi)} = \frac{1-\sin(\phi)}{1+\sin(\phi)}$ active earth pressure coefficient

$k_{p(\phi)} = \frac{1+\sin(\phi)}{1-\sin(\phi)}$ passive earth pressure coefficient

$$\sigma_{f(\phi)} = \left(\frac{\pi}{4} - \frac{\phi}{2}\right)$$

Passive soil pressure - a vertical wall pushes the soil with a thickness z figure 5.1.

This case corresponds to the working mode of a vertical knife moving in a horizontal direction

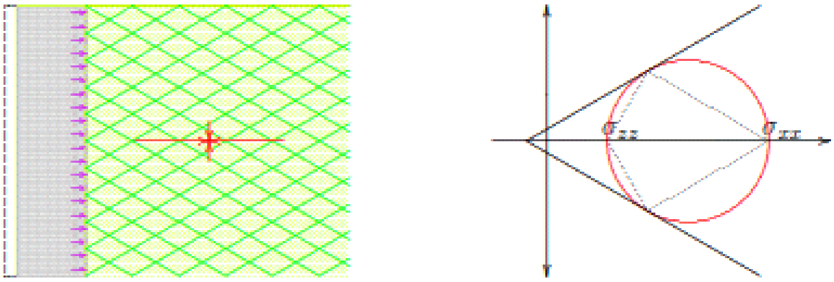


Figure 5.1. - ***Passive soil pressure on a vertical wall***

$$\sigma_{xp}(\rho_s, z, c_{oz}, \phi) = k_p(\phi) \cdot \rho_s \cdot g \cdot z + 2c_{oz} \cdot \sqrt{k_p(\phi)} \qquad (5.2.8)$$

linear variation with flow threshold $\tau_o = 2c_{oz} \cdot \sqrt{k_p(\phi)}$

Example for soil with characteristics

$\rho_s = 2900 \frac{kg}{m^3}$ $\phi = 5 \cdot \frac{\pi}{180}$ $c_{oz} = 2 \cdot 10^3$ p_a $\alpha_f(\phi).\frac{180}{\pi}$= 42.5 grade

$\sigma_{xpa}(\rho_s, 0.3, c_{oz}, \phi)$=1.452 x 10^4 P_a

$$\sigma_{xaa}(\rho_s, z_a, c_{oz}, \phi, h) = k_p(\phi) \cdot z_a + 2\frac{c_{oz}}{\rho_s \cdot g \cdot h} \cdot \sqrt{k_a(\phi)} \qquad (5.2.9\ a)$$

$$\sigma_{xpa}(\rho_s, z_a, c_{oz}, \phi, h) = k_p(\phi) \cdot z_a + 2\frac{c_{oz}}{\rho_s \cdot g \cdot h} \cdot \sqrt{k_p(\phi)} \qquad (5.2.9\ b)$$

The geometry of the chisel knife

The knife has width B and thickness sg (figure 5.2.)

Is considered B>sg.

The force is assumed to be uniformly distributed across the width of the blade.

The knife angle is β. The direction of the blade relative to the ground is α. Relative to the vertical, the direction of the knife is γ.

$$\alpha + \beta + \gamma = \frac{\pi}{2} \quad \gamma(\alpha, \beta) = \frac{\pi}{2} - \alpha - \beta \qquad (5.2.10)$$

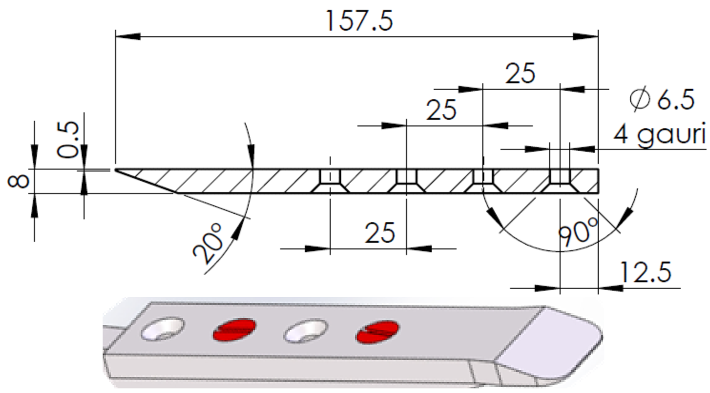


Figure 5.2. - ***The geometry of the chisel***

Two coordinate systems are attached:

- one fixed, attached to the ground with the origin at the tip of the blade, the initial entry of the blade into the ground and one mobile, attached to the blade moving relative to the ground at the speed v.

Axis Oy is in the direction of the blade width (B). The relation can be written between the two coordinate systems

x_s O_s^z ${}_xO_z$

$$x_s = x + v \cdot t$$

$$z_s = z - c(t) \qquad (5.2.11)$$

t - working time

c (t) - the vertical advance of the knife in the soil

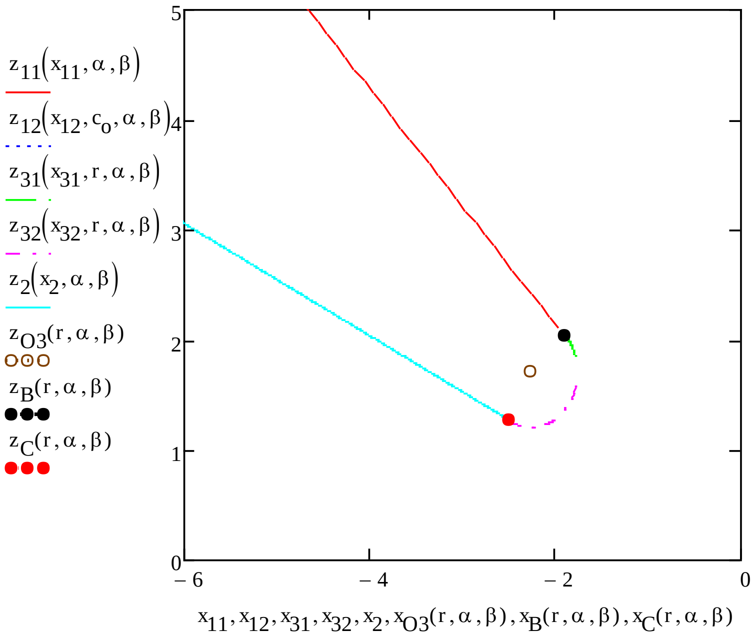
h - stabilized working depth

The knife has three edges:

- main one (1) in direct contact with the ground

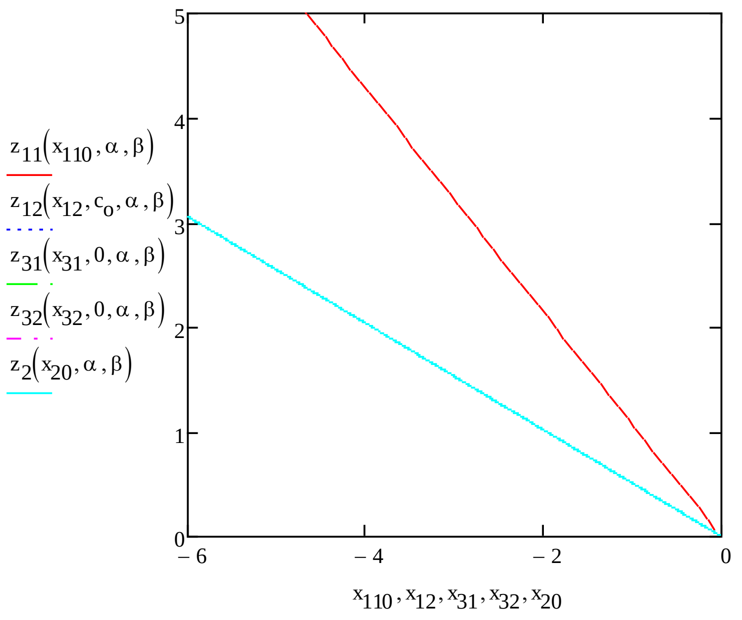
- a secondary one (2), behind the knife, in contact with the elastically deformed and recovered soil.

In figure 5.3. a,b show the profiles of the chisel-type knife edges, with a rounded or perfectly sharp tip. The profiles are determined by analytical geometry and made in Matchad, by dimensionless with respect to the working depth *h*.



a)

Radius rounded tip knife



b)

Figure 5.3. ***Geometry of chisel knife with rounded tip (a) and perfectly sharp tip (b)***

Perfectly sharp knife r = 0

The geometry of the chisel knife in the width direction:

Knife width

B_c = 30 mm

Blade width B_t = 32,5 mm

Length of the cutting edge in the direction of the axis L_t= 20

Knife connection radii in width R_c=7.5

The contact surface of the knife (pointed area) with the ground in the frontal plane (rectangle with the base Bt, width Hc, 2 circular sectors Sc with radius Rc and angle π/2)

$H_c = L_t - R_c$

$$A_{ct} = H_c.B_t.\frac{\pi \cdot R_c^{\ 2}}{4}.2 + R_c(B_t - 2R_c)$$

A_c=625.857 mm²

The total contact surface of the blade with the soil when the working depth h>Lt (normal working case)

$A_{ct}(h) = A_c + (h - L_t)B_c$

$A_{ct}(300) = 9.026x10^3$ mm²

The working length of the knife with the ground on the sharp area

$B_{cs} = 2H_c + \frac{2\pi R_c}{4}.2 + L_t - 2R_c =$

B_{cs}=53.562 mm

Total working length in normal operation (h>Lt

$B_{cs}(h)=B_{cs}+2(h-L_t)+B_c$

$B_{cs}(300)=643562$ mm

There are contact pressures on the entire working surface of the Act and in the presence of a sliding speed between the soil and the knife, wear of the knife will result.

Adhesive wear of the chisel bit

Wear behavior of the knife material (soil = visco-elasto-plastic matrix with free abrasive particles) wear rate U_z

$$U_z=\frac{d}{dt}f_n(x,t)=K_w.p_n(x,t).\ v_a \qquad (5.2.25)$$

Where $K_w\,\frac{mm^2}{N}$ is the specific wear parameter (coefficient) of the blade material in contact with the ground, dependent on the blade material and the abrasive and corrosive nature

If abrasive particles fixed in soil and with known geometry are considered, then the wear parameter can be correlated with the flow resistance of the knife material.

As a rule, it is determined experimentally for different soils.

$\frac{d}{dt}f_n(x,t)$ the variation of the profile along the normal direction, specific to the pressure direction $\frac{mm}{s}$

$$\frac{d}{dt}f_n(x,t)=\cos(\delta)\frac{d}{dt}f(x,t) \qquad (5.2.26)$$

δ - the angle of the tangent to the profile (edge curve) with the abscissa (Ox axis) and is determined based on the derivative of the profile

p_n- normal pressure on the tais

$v_a=\frac{v}{\cos(\delta)}$ the sliding speed between the nail and the soil in the direction of the nail mm/s

It results in the change in the blade profile over time, called the blade wear rate in the normal direction of the profile.$v_{uz}=\frac{d}{dt}f(x,t)=K_w.p_n(x,t).\left[1+\left(\frac{d}{dx}f(x,t)\right)^2\right].v$ *It is considered phenomenologically as for a small working time* Δt, the contact pressure on the knife depends only on the position of the contact point, position relative to the working depth. The linear intensity of wear is defined (I_{uh}) as the ratio of the elemental thickness of the worn layer (ds_{uz}) and the elemental friction length (d_{Lf}) which generated (caused)that wear and tear:

$$I_{uh}=\frac{ds_{uz}}{dL_f}=\frac{d(v_{uz}.t)}{d(v.t)}=\frac{v_{uz}}{v} \qquad (5.2.28)$$

$$I_{uh}=\frac{\frac{d}{dt}f(x,t)}{v}=K_w.\,p(x,t).\left[1+\left(\frac{d}{dx}f(x,t)\right)^2\right] \quad (5.2.29)$$

Based on specific soil parameters (E, ν, M, μ1), of the knife geometry and the working depth h, the quasi-stationary wear intensity is α,β,c_o,B,r_B, r

$$I_{uh}=\frac{v_{uz}}{v}=K_w.\,p.\left[1+\left(\frac{d}{dx}f(x,t)\right)^2\right]=K_w.\frac{N_1}{M}.\,p_a.\left[1+\left[\frac{d}{dxa}(z_a)\right]^2\right] \quad (5.2.30)$$

The coefficient of wear of the knife in a certain soil is defined

$$v_{uza}=\frac{I_{uh}}{K_w.\frac{N_1}{M}}=p_a.\left[1+\left[\frac{d}{dxa}(z_a)\right]^2\right]$$

$K_{wsc}=K_w.\frac{N_1}{M}$ dimensionless

and the dimensionless wear rate of the knife in a given soil has the expression

$$v_{uzcs}(x_a,t)=\frac{I_{uh}}{K_{wsc}}=p_a(x_a,t).\left[1+\left[\frac{d}{dxa}(z_a)\right]^2\right]=p_a(x_a,t).(1+dzax^2) \quad (5.2.31)$$

cu $dzax=\frac{d}{dxa}(z_a)$

The derivative of the knife profile dzax

on area 1.1 of the knife $dzax11=m_{u1}(\alpha,\beta)$ $dzax11=-1.072$

on area 1.2 of the knife $dzax12=m_{u2}(\alpha,\beta)$ $dzax12=-0.51$

Dimensionless wear rate, for normal working conditions (the pressure between the soil and the knife exceeds the critical cracking pressure of the soil from the tip to the crack abscissa)

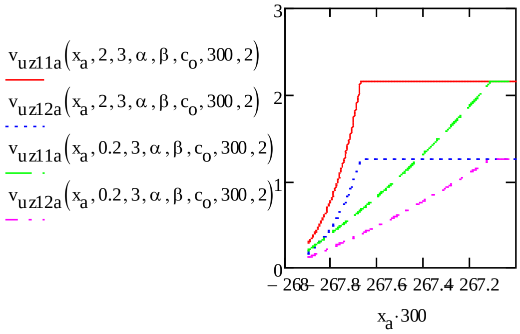
Edges 1.1 and 1.2 have different (derivative) slopes, thus resulting in different dimensionless wear rates:

$$v_{uz11a}(x_a,\mu_1,E,\alpha,\beta,c_o,h,p_{cr})=p_a(x_a,\mu_1,E,\alpha,\beta,c_o,h,p_{cr})\,(1+m_{u1}(\alpha,\beta)^2) \quad (5.2.31)$$

$$v_{uz12a}(x_a,\mu_1,E,\alpha,\beta,c_o,h,p_{cr})=p_a(x_a,\mu_1,E,\alpha,\beta,c_o,h,p_{cr})\,(1+m_{u2}(\alpha,\beta)^2) \quad (5.2.32)$$

In figure 5.4. the variation of the dimensionless wear rate on the active edge of the chisel knife (angle α=27 degrees, β=20 degrees, the cutting edge with co=23,39 mm), pentru operarea unui sol la adâncimea h=300 mm, characterized by μ1=2 si μ1=0.2, E=3 MPa, pcr= 2 MPa.

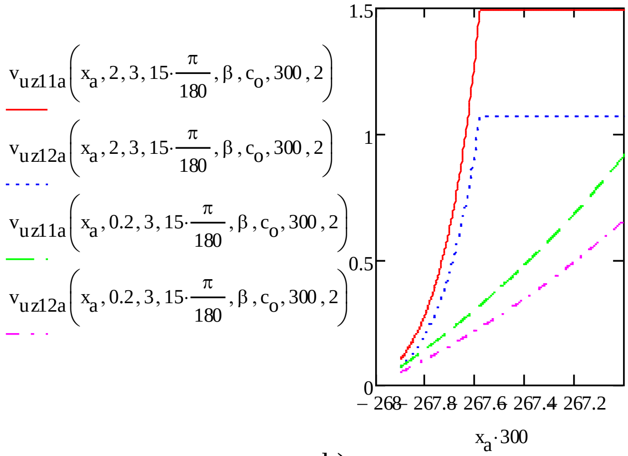
a)



$v_{uz12a}(x_a, \mu_1, E, \alpha, \beta, c_o, h, p_{cr}$

$\alpha \cdot \frac{180}{\pi} = 27$ $\beta \cdot \frac{180}{\pi} = 20$ $c_o = 23.39$

$v_{uz12a}(x_a, \mu_1, E, \alpha, \beta, c_o, h, p_{cr}$



b)

$v_{uz12a}(x_a, \mu_1, E, \alpha, \beta, c_o, h, p_{cr})$

c)

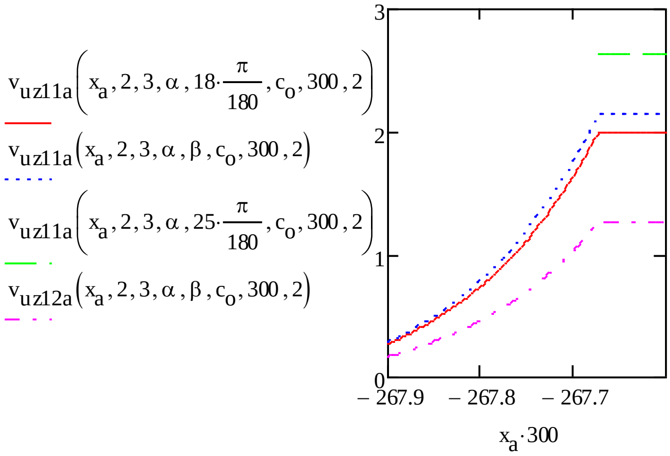


Figure 5.4. ***Knife wear rate distribution along the cutting edge for different mechanical soil characteristics (a), knife adjustment angles (b) and sharpening angles***

Since the thickness of the worn layer removed from the knife is small compared to the working depth (tens of mm versus tens of mm), the working depth is considered to be constant even as the knife wears. In this hypothesis, the position of the point on the blade at the ground entry (point A12) is the same with the same coordinates.

$s_{uz11}(x_a, \mu_1, E, \alpha, \beta, c_o, h, p_{cr}, K_w, v, \Delta t)$

Initial

$d_{AoO}(c_o)=c_o \qquad c_o = 23.39$

After the time Δt

$$c_{01}(\mu_1, E, \alpha, \beta, c_o, h, p_{cr}, K_w, v, \Delta t)=c_o - \frac{s_{uz11}\left(\frac{x_{A0(\alpha,\beta,c_O)}}{h}\right), \mu_1, E, \alpha, \beta, c_O, h, p_{cr}, K_W, v, \Delta t}{\tan(\beta)}$$

The coordinates of the new vertex

$$x_{O1}(\mu_1, E, \alpha, \beta, c_o, h, p_{cr}, K_w, v, \Delta t)=\frac{-s_{uz11}\left(\frac{x_{A0(\alpha,\beta,c_O)}}{h}\right), \mu_1, E, \alpha, \beta, c_O, h, p_{cr}, K_W, v, \Delta t}{\cos(\beta)}.\cos(\alpha)$$

$$z_{O1}(\mu_1, E, \alpha, \beta, c_o, h, p_{cr}, K_w, v, \Delta t)=-x_{O1}(\mu_1, E, \alpha, \beta, c_o, h, p_{cr}, K_w, v, \Delta t).\tan(\beta)$$

Analogously, the coordinates of all points on the profile are determined.

After 2 Δt

$$c_{O2}(\mu_1, E, \alpha, \beta, c_{olu}, h, p_{cr}, K_w, v, \Delta t)=1(\mu_1, E, \alpha, \beta, c_{olu}, h, p_{cr}, K_w, v, 2 \cdot \Delta t)$$

After

$$c_{on}(\mu_1, E, \alpha, \beta, c_{onu}, h, p_{cr}, K_w, v, \Delta t)=c_{o1}(\mu_1, E, \alpha, \beta, c_{olu}, h, p_{cr}, K_w, v, 2 \cdot \Delta t)$$

With this procedure, the coordinates of all points on the knife profile are determined.

It is exemplified in figure 5.5., as a detail, the shape of the tip of the perfectly sharpened knife after

Δt = 1000 s of work under the following conditions:

- The resistance (cracking) characteristics of the soil

$\mu_1 = 1\frac{mm^2}{N} \quad E = 3\frac{N}{mm^2} \quad p_{cr} = 1\frac{N}{mm^2}$

- The initial geometry of the knife

$\alpha = 0{,}471 \quad \beta = 0{,}349 \quad c_o=23.39$ mm

- The characteristic parameter of the wear of the knife material

$$K_w = 10^{-7}\frac{mm^2}{N}$$

- Working speed $v=5\frac{km}{h}=1389\frac{mm}{s}$
- Working depth h=300 mm

Detail in the area of the new tip of the used knife — Detail in the ground entry area

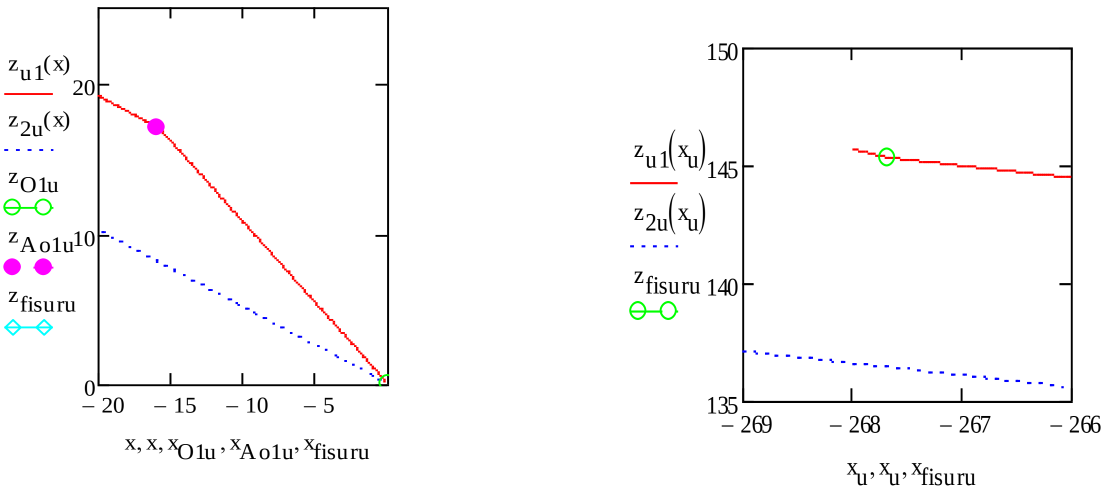


Figure 5.5. ***Detail of worn tip (a) and soil entry area (b) of perfectly sharp knife***

CHAPTER 6. CONCLUSIONS. CONTRIBUTIONS. PERSPECTIVES

From the analysis of bibliographic sources, own experiments and from the modeling of wear phenomena, specific to the active organs (knives) of agricultural machines, the following conclusions can be drawn

6.1. General conclusions.

1. The soil, as a work object, is, from a rheological point of view, a complex material in continuous change and which has a resistance limit determined according to the Mohr-Coulomb criterion. The defining parameters for the characterization of the mechanical properties of the soil, useful for tribological phenomena, are the cohesion and the angle of the natural slope, an angle that highlights the internal friction.

2The cohesion and friction angle between sand and knife are determined for dry and wet sand on a CETRE-UMT2 multifunctional tribometer, by the penetration method. The test piece has the shape of a real knife and represents a model reduced to a scale of 1:8. The material and surface quality of the test piece are similar to those of the real chisel knife. The approximation of the experimental results regarding the penetration force of the knife specimen, with polynomial functions of the 2nd degree, allows the determination of the energy during penetration and the highlighting of the effect of water adsorbed by sand and the effect of repeated penetration in the same place. The experimental results regarding the penetration force confirm the theoretical model regarding the equation of the knife with a vertical wall subjected to the action of the soil.

3. The wear of the plow blades, made of materials with new heat treatments and deposits with layers in different directions, has an approximately constant speed. The presented experiments were carried out at INMA Baneasa (paragraph 2.1) and confirm the theoretical model regarding adhesion wear, developed in chapter .5

4. The wear of chisel knives in dry and wet sand has a linear evolution, the rate of wear being relatively constant. This speed is different for operation in dry sand and operation in wet sand and for different materials. 3 materials C45, hardened C45 and E295 were tested. The determinations were made at INMA Baneasa and Univ. Technique from Cluj-Napoca.

5. The theoretical model regarding the stresses that act on the knife during penetration is an adaptation of the case of a vertical or inclined wall that supports a half-space of the earth.

6. The use of analytical geometry to describe the edges of the chisel knife (linear, circular functions), allows the description of the theoretical model of adhesive wear with the use of dimensionless parameters.

7. The essential hypothesis of the theoretical model of adhesive wear is the condition of continuous contact between the knife and the soil, with elastic and plastic deformations of the soil. The differential equation of the contact pressure is of degree 1, linear type, and is solved with the MATCHAD 15 program.

8. The theoretical adhesive wear rate is maximum at the tip and near it. The theoretical shape of the used tip is similar to the used tips shown in photographs from many bibliographic sources. For tips with a circular edge, connected to linear edges of different slopes, the radius of the tip increases in the process of wear and the process of cracking the soil in order to form the furrow worsens.

9. The theoretical model of knife abrasion wear takes into account three ways of surface deformation by the stiffened particles in the soil matrix: elastic deformation ("shakedown"), edging ("ploughing") and cutting ("cutting").

10. For the analysis of the contact between a rigid abrasive particle and the elastoplastic surface of the knife, the classic theories of elastic contact (Hertz) and the conditions for the appearance of plastic deformations for materials with or without roughness are used.

11. Define the speed and intensity of abrasive wear of the knife as a function of the mechanical properties of the material and the geometry of the abrasive particle.

12. For the case of abrasive particles as random variables, the case of the height of the spherical caps of the particles, as a random variable, with the radius of the caps of constant radius is analyzed.

13. The state of deformation of the knife surface is assessed by the soil-knife plasticity index.

14. To highlight the effect of the "neighborhood" of two hard, stiffened particles on the wear of the knife, the Xie model is adapted, according to which there is a critical distance between two neighboring traces at which microshear occurs.

15. The main parameters in the friction process between the knife and the soil with particles stiffened in the matrix are the Archard wear coefficient and the deformation component of the friction coefficient. These parameters are explained for the three forms of deformation.

16. Archard parameters and the deformation component of the friction coefficient are detailed for different statistical parameters of the abrasive particles and deterministic characteristics of the material properties.

6.2. Contributions brought by this thesis

A) in the documentary field

- The bibliographic study regarding the physical properties and mechanical characteristics of the soil, with the influence on the working organs of the agricultural machines.

- The bibiographical study of the penetration resistance of soils and usable devices.

- The study of resistance to abrasive and adhesive wear of materials.

- Synthesis regarding the definition of agricultural machine bodies with intensive wear processes and with removal from function as a result of excessive wear.

- Analysis of the effects of hardening the surfaces of the plow furrows for plowing on the wear of the furrows, for the experiments done before the thesis, at INMA.

B) in the field of experimental research and used stands

- Creation of a device for mounting chisel-type knives for a stand at the Technical University of Cluj Napoca.

- Participation in the realization of a new test stand for the use of chisel-type knives in different types of soils, stand made at INMA.

- Classification of sand tested with calibrated sieves.

- Determining the wear rates of chisel-type knives, made of 3 materials, in dry sand and in wet sand, highlighting the role of humidity on the increase in wear rate.

- Determining the cohesion strength of dry and wet sand and the friction coefficient between the knife and the sand, using a new method - the test knife penetration method.

- Adaptation of the CETRE-UMT2 tribometer for determining soil resistance parameters (cohesion, soil knife friction).

C) In the theoretical field and computer programs

- Deducing the dependence of the force of penetration into the soil on the depth, on the mechanical properties of the soil (cohesion, angle of internal friction - angle of natural slope) and on the friction between the knife and the soil.

- The ingenious adaptation of a model of wear through adhesion to the particular case of knife-soil and the use of dimensionless parameters as a similarity criterion.

- The realization of a new model of abrasive wear of the blades of tillage machines with abrasive particles fixed in the matrix.

- Creation of 3 calculation programs in the MATCHAD 14 utility regarding wear by adhesion, wear by abrasion and forces and stresses in the penetration process.

6.3. Perspectives

The work opens several perspectives for further research:

- taking into account the corrosive effect of the soil on global wear
- the cumulative effect of adhesion wear - abrasion and corrosion
- technological and geometric solutions for increasing wear resistance.

7. List of works

CARDEI P., VLADUTOIU L., CHISIU G., TUDOR A, SORICA C., GHERES M., GHEORGHE G. AND MURARU S. (2018), Research on friction influence on the working process of agricultural machines for soil tillage, IOP Conference Series: Materials Science and Engineering, Vol. 444 (2);

VLĂDUŢOIU L, T. L. FECHETE, I. A. GRIGORE, E. SORICA, A. PETRE, O. D. CRISTEA (2020), Experimental researches on determination of wear of working part of chisel type made of three types of materials, Scientific Papers INMATEH - Agricultural Engineering appearing in print (ISSN 2068 – 4215) and online (ISSN 2068 – 2239), Volume 62/No.3/2020, p.p. 269-276;

ANDREI TUDOR, LAURENTIU VLADUTOIU, SORIN STEFAN BIRIS (2014), Wearing model of soil processing machines knives", at the International Tribology Conference organized by "Balkan Tribological Association" between 30.10-01.11.2014 in Sinaia;

VLADUTOIU L., A.TUDOR, S.BIRIS, V.VLADUT (2014), A model of wear of agricultural machinery knives" in the 5th ICMEN and 11th THE "A" Coatings International Conferences Salonik, Greece;

VLADUŢOIU L., VLADUŢ V., VOICULESCU I., MATACHE M., RADU O., BIRIŞ S., VOICEA I., PARASCHIV G., ATANASOV AT., USENKO M. (2015), "The increase of active bodies of

agricultural machines in work by hardening", during the 43rd International Symposium "Actual Tasks on Agricultural Engineering" conference, during March/2015;

VLĂDUŢOIU L., A. TUDOR, V. VLADUT, C. MURARU, O. RADU, A. PETCU (2015), **„**Apparatus and equipment for determination of soil physical and mechanical characteristics", în cadrul conferintei 4 th International conference on thermal equipment, renewable energy and rural development, perioada 04-06.06.2015;

VLĂDUŢOIU L, CROITORU ST., A. TUDOR, ATANASOV AT.,V. VLADUT, S.BIRIS, O. RADU, DUMITRU I. (2015), **„**Optimization of soil works for maintaining a good agrophysics state of the soil**",** în cadrul Conferinței Internationale Research people and actual tasks on multidisciplinary sciences, volume 1 Agriculture and Veterinary medicine Technical sciences, Processing&Post Harvest Technology and Logistics, Power and machinery, Lozenc, bulgaria, 24-28 iunie 2015;

VLADUȚOIU Laurențiu, TUDOR Andrei, FECHETE-TUTUNARU Lucian, GRIGORE Iulia, SORICĂ Elena, DETERMINATION OF THE WEAR OF THE ACTIVE ORGANS OF A SCARIFIER, IN ACCELERATED REGIME, FUNCTION OF THE TYPE OF MATERIAL USED, International Fair of Inventions and Practical Ideas Invent–Invest Constantin-Marin Antohi , 12th edition, December 10, 2021 - Iasi, Romania

Vladutoiu, L., Andrei, T., Fechete, L., Marin, E., Vladut, V., Matache, M., Dumitru, I.. "DETERMINING THE WEAR OF ACTIVE ORGANS FOR PROCESSING SOIL DEPENDING ON THE WORKING DEPTH", Annals of the University of Craiova -2016.

Bibliographie (Extras)

1. **Braharu D., Băjenaru S., Vlăduţ V., Matache M. 2007.** *Researches regarding materials selection of the operating parts manufacturing for soil cultivation*. Materials and treatments used for theirs design, Annals of University of Craiova - Agriculture, Montanology, Survey, vol. XXXVII / B 2007, Craiova - Romania, pag. 48-55, ISSN 1841-8317;
2. **Cardei P., Vladutoiu L., Chisiu G., Tudor A, Sorica C., Gheres M., Gheorghe G. And Muraru S. 2018**, *Research on friction influence on the working process of agricultural machines for soil tillage*, IOP Conference Series: Materials Science and Engineering, Vol. **444 (2)**;
3. **Dokuchaev VV.,** 1883, *Cernoziom rusesc*: (Raport către Societatea Economică Liberă). Sankt Petersburg: tip. Decleron și Evdokimov, 376 p;

4. **Epure (Totolici) I.Ioana Cătălina, 2011**. ”*Modelarea teoretică şi experimentală a procesului de afânare-scarificare a solului*”, Teza doctorat Universitatea TRANSILVANIA din Braşov - Facultatea de Alimentaţie şi Turism, Brasov;
5. **Fechete L.V. 2008**. „*Cercetari privind optimizarea procesului de prelucrare mecanica a solului”*, Teza de doctorat, Universitatea Tehnică Cluj-Napoca;
6. **Matache M. și alții 2006**, Proiect “*Materiale de fricţiune complexe pe bază de fier şi/sau cupru pentru sistemele de frânare ale maşinilor şi echipamentelor destinate agriculturii realizate prin tehnologii integrate*”, Program CEEX, INMA Bucuresti;
7. **Meng H.C., Ludema K.C., 1995**, *Wear models and predictive equations: their form and content*, ELSEVIER Wear 181-183 (1995) 443-457, SSDI 0043-1648(94)07102-O;
8. **Tanco Corneliu 2011**, “*Cercetări privind imbunatatirea calitativa a partilor active, supuse uzurii la utilajele agricole aplicand tehnologii de incarcare prin sudare*” teza de doctorat, Brasov;
9. **Ţenu I., Jităreanu1 G., Muraru-Ionel C., Cojocariu1 P., Muraru V.M. 2009,** *The impact of mechanization technologies on soil.* Environmental Engineering and Management Journal 8(5), pag. 1263-1267;
10. **Tomescu D., Mitrol C., Florea St., 1975**, *Repararea utilajului agricol*, Bucureşti: CERES, 340 pag.;
11. **Visa I., Rus F. și alții 2009**, *Studiu privind sistemele complexe şi metodologiile utilizate pentru determinarea caracteristicilor fizico mecanice ale solurilor*, Proiect ”Cercetari privind promovarea unui sistem complex pentru evaluarea caracteristicilor fizico mecanice ale solurilor in vederea cresterii sigurantei si securitatii productiei agricole”, Universitatea Transilvania din Braşov;
12. **Vlăduţoiu L, T. L. Fechete, I. A. Grigore, E. Sorica, A. Petre, O. D. Cristea 2020**, *Experimental researches on determination of wear of working part of chisel type made of three types of materials*, Scientific Papers INMATEH - Agricultural Engineering appearing in print (ISSN 2068 – 4215) and on-line (ISSN 2068 – 2239), Volume **62**/No.3/2020, p.p. 269-276;
13. **Vlăduțoiu L., Tudor A., Fechete T. L., Grigore I., Sorică E., 2021**. *Determinarea Uzurii Organelor Active Ale Unui Scarificator, În Regim Accelerat, Funcție De Tipul De Material Utilizat*, Târgul Internațional de Invenții și Idei Practice Invent–Invest Constantin-Marin Antohi, ediția a 12-a, 10 Decembrie 2021 - Iași, România;