Penetration tests to study the mechanical tribological properties of chisel type knife

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Abstract. The goal of this study was to analyze the behaviour of chisel knife type penetration in a certain type of sand. A series of penetration tests were carried out with chisel knife type, the answer to penetration depending mainly on nature, shape, size of knife and operating parameters such as speed, depth and working conditions. Tests were conducted in work conditions with wet sand and dry sand and determined force of resistance to penetration of the chisel knife type to a certain depth.

1. Introduction
The working components of agricultural machinery are in direct contact with an abrasive mass. The wear of these components depends of the type of soil [1]. Since these working parts are subjected to different high loads the wear intensity is much higher than in other parts of the equipment. These are called large bodies of wear [2],[3],[4]. Construction of a chisel is shown in figure 1a. The active bodies are changeable and of various shapes, most often of the chisel type as in figure 1b.

Figure 1. Agricultural machinery: (a) chisel; (b) chisel knife type.
The chisel type soil breaking machines are designed to perform the soil loosening without overturning the furrow in order to increase the loosen layer thickness, for raising the capacity of water ingress [5].

2. Theoretical model
The cutting edge sharpness is particularly important in the chisel geometry. The wear of components of soil-tilling machinery is directly influenced by the mechanical properties of the soil [1]. The intrinsic properties of soil are considered the cohesion (c) and the internal friction angle (ϕ) [7],[8],[9]. We consider a model of chisel (figure 2) with the vertical (σz) and horizontal (σx) stresses [7].

\[
\begin{align*}
\sigma_z &= \gamma z \\
\sigma_{xp} &= k_p \sigma_z + 2c_0 \sqrt{k_p} \\
\sigma_{xa} &= k_a \sigma_z - 2c_0 k_a
\end{align*}
\]  

(1)

where \( \gamma \) is volumetric weight; \( z \)- depth below soil surface; \( k_a, k_p \) coefficients of active or passive earth pressure.

In penetration phenomena of chisel in the soil are distinguish two cases:
- penetration in zone of cutter \((0, h_1)\), (figure 3 a);
- penetration in central zone of chisel \((0, h_2)\), (figure 3 b).

![Figure 2. Geometry details of the chisel knife.](image-url)

![Figure 3. Stresses on the wall of knife: (a) knife zone; (b) central zone.](image-url)
The penetration force is obtained by the mechanical equilibrium. Thus, for first case:
- in *knife zone* (symbol 1 in figure 1 and figure 3 (a))

\[
F_{a_{1a}} = h_a^2 \cdot \left[ \tan(\alpha) + \mu_c \cdot \left( \sin(\alpha) + k_a \cos(\alpha) - \frac{4c_{0a} \sqrt{k_a} \cdot \cos(\alpha)}{h_a} \right) \right] \quad (2a)
\]

for the case of active earth pressure (soil is expected to slide in download direction, along the surface of cutter);

\[
F_{a_{11p}} = h_a^2 \cdot \left[ \tan(\alpha) + \mu_c \cdot \left( \sin(\alpha) + k_p \cos(\alpha) + \frac{4c_{0a} \sqrt{k_p} \cdot \cos(\alpha)}{h_a} \right) \right] \quad (2b)
\]

for the case of passive earth pressure (soil is expected to slide in upward direction, along the surface of cutter);
- in *lateral zone of knife* (symbol 2 in figure 2 and figure 3 (a))

\[
\begin{align*}
F_{a_{12a}} &= \mu_c \cdot l \cdot h_a^2 \cdot \left( k_a - \frac{4c_{0a} \sqrt{k_a}}{h_a} \right) \\
F_{a_{12p}} &= \mu_c \cdot l \cdot h_a^2 \cdot \left( k_p + \frac{4c_{0a} \sqrt{k_p}}{h_a} \right)
\end{align*}
\]

(3)

- in *frontal zone of knife* (symbol 3 figure 2, 3 (a) two surfaces)

\[
\begin{align*}
F_{a_{13a}} &= 2\mu_c \tan(\alpha) \cdot h_{1a} h_a \left( 1 - \frac{2}{3} k_a h_a^2 - 4c_{0a} \sqrt{k_a} + 2c_{0a} \sqrt{k_a} \cdot h_a \right) \\
F_{a_{13p}} &= 2\mu_c \tan(\alpha) \cdot h_{1a} h_a \left( 1 - \frac{2}{3} k_p h_a^2 + 4c_{0a} \sqrt{k_p} - 2c_{0a} \sqrt{k_p} \cdot h_a \right)
\end{align*}
\]

(4)

The total dimensionless force in penetration direction (*z*), for first case (*knife zone*) is:

\[
\begin{align*}
F_{a_{1a}} &= F_{a_{11a}} + F_{a_{12a}} + F_{a_{13a}} \\
F_{a_{1p}} &= F_{a_{11p}} + F_{a_{12p}} + F_{a_{13p}}
\end{align*}
\]

(5)

where \( \mu_c \) is the friction coefficient between chisel and soil; \( \alpha \)- the cutter angle (figure 2, figure 3 (a) and 3 (b)), and dimensionless force penetration parameter \( F_a \), geometrical parameters \( (h_{1a} \ h_a) \), dimensionless cohesion parameter \( (c_{oa}) \) respectively:

\[
\begin{align*}
F_a &= \frac{F}{\frac{1}{2} \rho h_1^2 B} \\
\rho &= \frac{h_{1a}}{B} \\
h &= \frac{h_a}{h_{1a}} \\
c_{0a} &= \frac{c_0}{\rho h_1}
\end{align*}
\]

(6)
If the coefficient of active or passive earth pressure \((k_a), (k_b)\) respectively \([1],[5]\) is:

\[
\begin{align*}
k_a &= \frac{1 - \sin(\phi)}{1 + \sin(\phi)} \\
k_p &= \frac{1 + \sin(\phi)}{1 - \sin(\phi)}
\end{align*}
\]  

(7)

it is obtained the penetration force of chisel model for the first case.

Thus, figure 4 shows the dimensionless penetration force as a function to depth for some values of friction internal angle \((\Phi)\), friction coefficient \((\mu_c)\) and dimensionless cohesion parameter \((c_{oa})\).

**Figure 4.** The dimensionless penetration force in knife zone for some soil types (active pressure earth).

The figure 5 shows that fracture of soil appears when the penetration force will be zero. In this case, is observed the positive effect of chisel for the fragmentation of soils with high cohesion.

In the second case \((h_1 < h < h_2)\), the penetration force is determined similarly:

\[
\begin{align*}
F_{a1a} &= F_{a1b} \\
F_{a2a} &= \mu_c \left(k_a - 4c_{oa}\sqrt{k_a}\right) + 2\mu_c \left(h_a - 1\right) - 4c_{oa}\sqrt{k_a}\left(h_a - 1\right) \\
F_{a2p} &= F_{a2p} + F_{a2p} + F_{a2p} \\
F_{a3a} &= 2\mu_c \tan(\alpha)h_{la} \left(1 - \frac{2}{3}k_a - 4c_{oa}\sqrt{k_a} + 2c_{oa}\sqrt{k_a} + 2\mu_c \tan(\alpha)h_{la}\left(k_a - h_a - 1\right) - 4c_{oa}\sqrt{k_a}\left(h_a - 1\right)\right)
\end{align*}
\]  

(8)

The chisel penetration force in soil is defined by:

\[
F_{a1a} = \begin{cases} 
F_{a1a}, & \text{if } 0 \leq h_a \leq 1 \\
F_{a1a}^{-1}, & \text{if } h_a > 1 
\end{cases}
\]  

(9)

for active earth pressure and

\[
F_{a1p} = \begin{cases} 
F_{a1p}, & \text{if } 0 \leq h_a \leq 1 \\
F_{a1p}^{-1}, & \text{if } h_a > 1 
\end{cases}
\]  

(10)

for passive earth pressure.

The figures 6, 7 and 8 show the penetration dimensionless forces for some soils in contact with steel material of chisel sample.
3. Experimental procedure

The penetration tests were performed with the UMT 2 tribometer (BRUKER® former CETF, USA) (figure 9). This apparatus can control and measure the applied loads, displacements and velocities of the indenter. Hard indenter used in these tests was made of steel, with prismatic form and an angle of $20^0$.

For testing the sand at the penetration resistance we used a plastic box to put the sample of sands. The plastic box was filled with sand with a quantity of 0.168 kg which was levelled to the same height over the entire tank. The surface area of the sand is 36 mm $\times$ 85 mm and the thickness is 32 mm.
Table 1. Features plastic box with and without sand.

|               | Empty box | Sand | Sand box |
|---------------|-----------|------|----------|
| Weight (kg)   |           |      |          |
| Dry           | 0.114     | 0.168| 0.324    |
| Wet           |           | 0.282| 0.438    |

For the performed researches a certain type of sand was chosen sand that formed the basis of tool-soil interaction study, this being characterized by the lack of cohesion and high abrasive property.

The maximum load was limited to 19 N assuming that a 20 N (2 kg) force sensor is installed in the tribometer UMT 2. The penetration velocity was 2 mm/s. All tests were performed with penetration depths at 8 mm into the sand. Two test conditions were employed: dry and wet contact. These conditions were used in order to account for the effect of penetration lubrication. Wet contact tests were performed using water, in order to replicate the *in vivo* environment. The plastic box was filled with 0.156 kg of water.

The penetration tests were carried out with chisel knife type in two conditions: same area and different area of the sand.

There have been performed 10 tests for each work condition while eliminating outliers, out of which nine tests remained valid.

4. Experimental results

Figure 10 shows the load-displacement curves for the sand material in contact with the hard indenter, under wet conditions. Figure 11 shows the load-displacement curves for the sand material in contact with the hard indenter, under dry conditions.

In figures 10, 11, 12 were used the following notation:
- T1 – the average of penetrations tests in the same area;
- T2 - the average of penetrations tests in different area;
- T3 – the average of penetrations tests in the same area;
- T4 - the average of penetrations tests in different areas.

**Figure 10.** The experimental load-displacement curves for average of penetrations tests with chisel type knife under wet conditions.

**Figure 11.** The experimental load-displacement curves for average of penetrations tests with chisel type knife under dry conditions.

Figure 12 shows the load-displacement curves for the sand material in contact with the hard indenter under dry and wet conditions.

The response of the surface to penetrations for different lubrication conditions is influenced by the mechanical properties of the material and it is noticeable in all figures. For example, the peak penetration force of 3.92 N for sand tested in the same area is higher than the peak penetration force of 3.32 N for sand tested in different areas, in dry condition tests. The peak penetration force of 1 N for
sand tested in the same area is approximated the same value for the peak penetration force of 0.89 N for sand tested in different areas, in wet conditions.

The penetration force for dry contact is always greater than for wet contact, regardless of material type.

![Average dry sand and wet tests](image)

**Figure 12.** The experimental load-displacement curves for average of penetrations tests with chisel type knife under dry and wet conditions.

## 5. Conclusions

The answer to penetration mainly depends on nature, shape, size of knife and operating parameters such as speed, depth and working conditions.

Maximum penetration force in the same area for dry sand is higher than maximum penetration force in different areas for dry sand. Maximum penetration force in the same area for wet sand has approximately the same value as maximum penetration force in different areas for wet sand.

Sand humidity has influenced the resistance force at penetration, therefore the penetration force in case of dry sand is higher than penetration force for wet sand.

## References

[1] Braharu D, Băjenaru S, Vlăduț V and 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 XXXVII (B) 48-55

[2] Matache M, Ganga M, Mihai M, Postelnicu E and Bajenaru S 2008 Researches regarding determination of mechanical and wear characteristics for friction materials Scientific Papers INMATEH 28 120-123

[3] Tanco C, Heraşcu (Roşca) M, Radu (Hanea) C Nicolae I 2011 Research on reconditioning agricultural plough by applying welding hardfacing The 7th Intern. Conf. on Materials Science and Engineering – BRAMAT 69-72

[4] Mueller M, Chotěborský R, Valášek P and Hloch S 2013 Unusual possibility of wear resistance increase research in the sphere of soil cultivation Technical Gazette 20 (4) 641-646

[5] Jankauskas V, Katinas E, Skirkus R and Aleknevičienė V 2014 The method of hardening soil rippers by surfacing and technical-economic assessment J. Fric. Wear 35 (4) 270–277

[6] Verruijt A 2002 *Soil mechanics* ed Barends F B J and Steijger P M P C (Delft: CRC Pres)

[7] Keller T Lamandé M 2010 Challenges in the development of analytical soil compaction models Soil Till. Res. 111 54-64
[8] Cole D M, Mathisen L U, Hopkins M A and Knapp B R 2010 Normal and sliding contact experiments on gneiss *Granul. Matter* **12** (1) 69–86

[9] Naderi B M, Alimardani R, Hemmat A, Sharifi A, Keyhani A, Tekeste M Z and Keller T 2013 3D finite element simulation of a single-tip horizontal penetrometer–soil interaction. Part I: Development of the model and evaluation of the model parameters *Soil Till. Res.* **134** 153-162

[10] Chişiu G, Tiberiu L Tudor A 2011 Indentation tests to study the mechanical tribological properties of UHMWPE *UPB Scientifical Bulletin* Series D **73** (4) 209-222

[11] Chişiu G and Tudor A 2014 Wear characteristics of UHMW polyethylene by scratching method *J Balk Tribol Assoc* **20** (1) 138–150