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.

(a)　　　　　　　　　　(b)

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_o) and the internal friction angle (ϕ) [7],[8],[9]. We consider a model of chisel (figure 2) with the vertical (σ_z) and horizontal (σ_x) stresses [7].

$$\begin{cases} \sigma_z = \gamma z \\ \sigma_{xp} = k_p \sigma_z + 2c_0 \sqrt{k_p} \\ \sigma_{xa} = k_a \sigma_z - 2c_0 \sqrt{k_a} \end{cases} \tag{1}$$
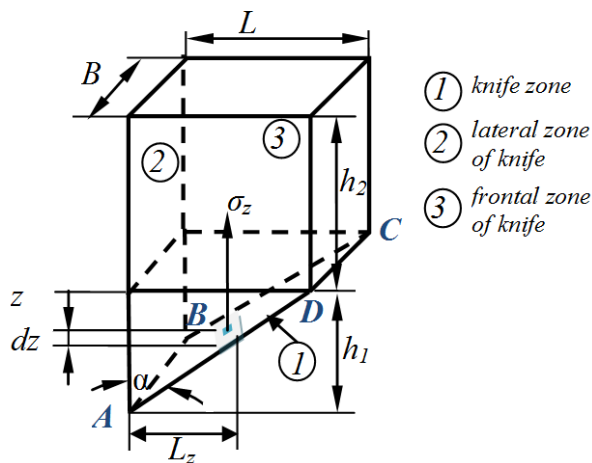

Figure 2. Geometry details of the chisel knife.

where γ 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).

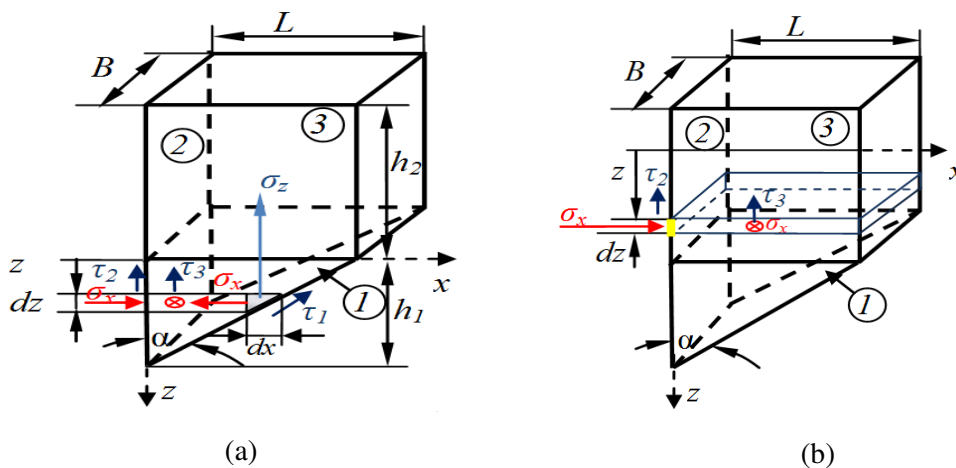(a)   (b)

Figure 3. Stresses on the wall of knife: (a) knife zone; (b) central zone.

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)

$$F_{a11a} = h_a^2 \cdot \left[\tan(\alpha) + \mu_c \cdot \left(\sin(\alpha) + k_a \cos(\alpha) - \frac{4c_{0a}\sqrt{k_a} \cdot \cos(\alpha)}{h_a} \right) \right]$$

(2a)

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

$$F_{a11p} = h_a^2 \cdot \left[\tan(\alpha) + \mu_c \cdot \left(\sin(\alpha) + k_p \cos(\alpha) + \frac{4c_{0a}\sqrt{k_a} \cdot \cos(\alpha)}{h_a} \right) \right]$$

(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))

$$\begin{cases} F_{a12a} = \mu_c \cdot l \cdot h_a^2 \cdot \left(k_a - \frac{4c_{0a}\sqrt{k_a}}{h_a} \right) \\ F_{a12p} = \mu_c \cdot l \cdot h_a^2 \left(k_p + \frac{4c_{0a}\sqrt{k_p}}{h_a} \right) \end{cases}$$

(3)

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

$$\begin{cases} F_{a13a} = 2\mu_c \tan(\alpha) l \cdot h_{1a} h_a \cdot \left(1 - \frac{2}{3} k_a h_a^2 - 4c_{0a}\sqrt{k_a} + 2c_{0a}\sqrt{k_a} \cdot h_a \right) \\ F_{a13p} = 2\mu_c \tan(\alpha) l \cdot h_{1a} h_a \left(1 - \frac{2}{3} k_p h_a^2 + 4c_{0a}\sqrt{k_p} - 2c_{0a}\sqrt{k_p} \cdot h_a \right) \end{cases}$$

(4)

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

$$\begin{cases} F_{az1a} = F_{a11a} + F_{a12a} + F_{a13a} \\ F_{az1p} = F_{a11p} + F_{a12p} + F_{a13p} \end{cases}$$

(5)

where μ_c is the friction coefficient between chisel and soil; α- 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:

$$\begin{cases} F_a = \dfrac{F}{\frac{1}{2}\gamma h_1^2 B} \\ h_{1a} = \dfrac{h_1}{B} \\ h_a = \dfrac{h}{h_1} \\ c_{0a} = \dfrac{c_0}{\gamma h_1} \end{cases}$$

(6)

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

$$\begin{cases} k_a = \dfrac{1 - \sin(\phi)}{1 + \sin(\phi)} \\ k_p = \dfrac{1 + \sin(\phi)}{1 - \sin(\phi)} \end{cases} \tag{7}$$

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 (Φ), friction coefficient (μ_c) and dimensionless cohesion parameter (c_{oa}).
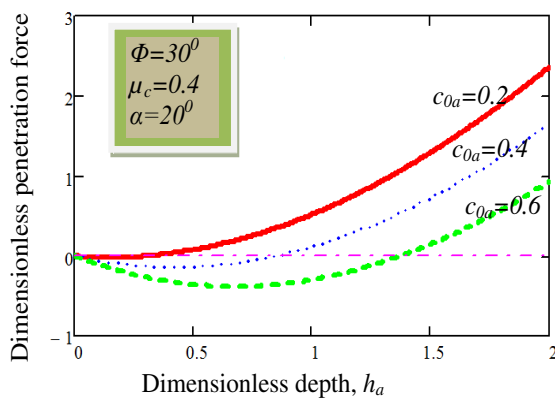

Figure 4. The dimensionless penetration force in knife zone for some soil types (active pressure earth).
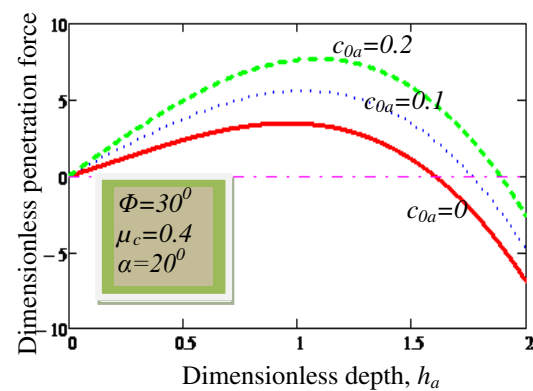
Figure 5. The dimensionless penetration force in knife zone for some soil types (passive pressure earth).

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:

$$\begin{cases} F_{a21a} = F_{a11a} \\ F_{a22a} = \mu_c \cdot \left(k_a - 4c_{0a}\sqrt{k_a}\right) + 2\mu_c \left(k_a\left(h_a^2 - 1\right) - 4c_{0a}\sqrt{k_a}\left(h_a - 1\right)\right) \\ F_{az2p} = F_{a21p} + F_{a22p} + F_{a23p} \\ F_{a23a} = 2\mu_c \tan(\alpha) \cdot h_{1a}\left(1 - \dfrac{2}{3}k_a - 4c_{0a}\sqrt{k_a} + 2c_{0a}\sqrt{k_a} + 2\mu_c \tan(\alpha) \cdot h_{1a}\left(k_a\left(h_a^2 - 1\right) - 4c_{0a}\sqrt{k_a}\left(h_a - 1\right)\right)\right) \end{cases} \tag{8}$$

The chisel penetration force in soil is defined by:

$$F_{aza} = \begin{vmatrix} F_{az1a}, & if \ \ 0 \le h_a \le 1 \\ F_{az2a}, & if \ \ h_a > 1 \end{vmatrix} \tag{9}$$

for active earth pressure and

$$F_{azp} = \begin{vmatrix} F_{az1p}, & if \ \ 0 \le h_a \le 1 \\ F_{az2p}, & if \ \ h_a > 1 \end{vmatrix} \tag{10}$$

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.
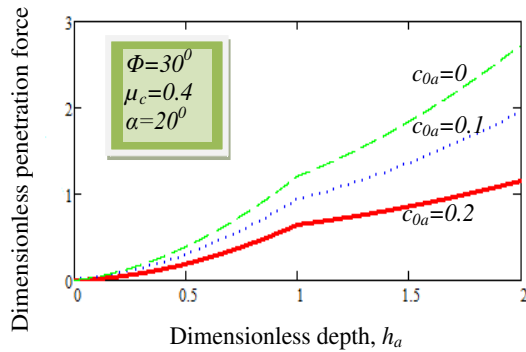
Figure 6. The dimensionless penetration force of chisel in sand with some friction angle (active pressure earth).
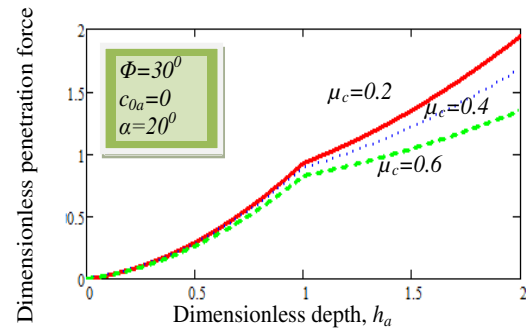

Figure 7. The dimensionless penetration force of chisel in sand with some friction coefficient between sand and chisel (active pressure earth).
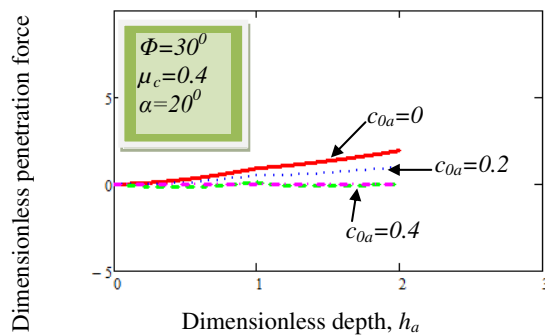

Figure 8. The dimensionless penetration force of chisel in soil with some cohesion strength (active pressure earth).

3. Experimental procedure

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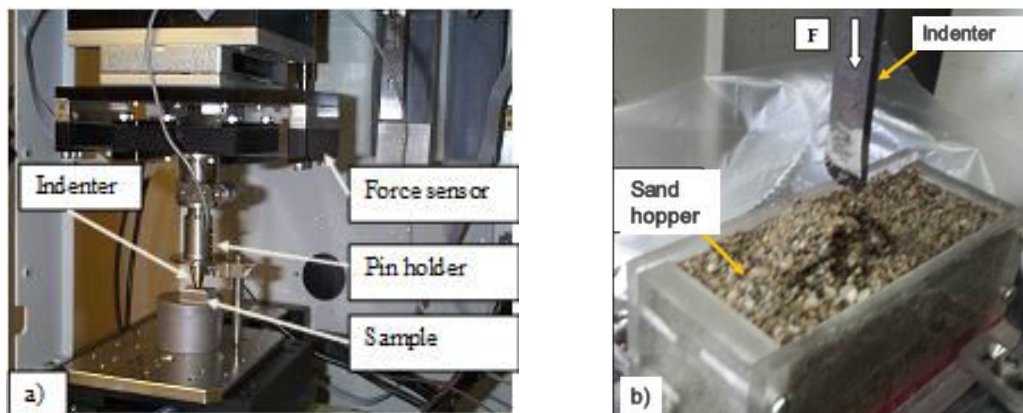

Figure 9. Penetration test details: (a) Penetration test set-up of UMT 2; (b) Schematic of penetration test set-up [10][11].

For testing the sand at the penetration resistance we used a plastics 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 × 85 mm and the thickness is 32 mm.

Table 1. Features plastic box with and without sand.

	Empty box	Sand		Sand box	
		Dry	Wet	Dry	Wet
Weight (kg)	0.114	0.168	0.324	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;
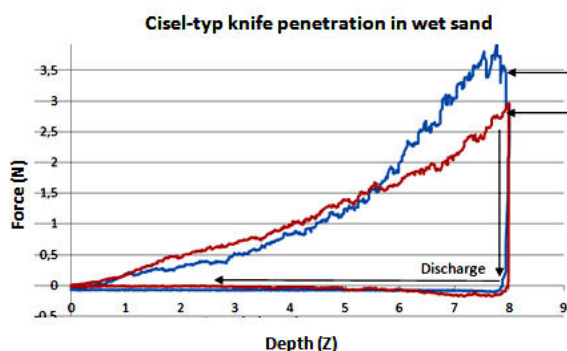- T4 - the average of penetrations tests in different areas.

Figure 10. The experimental load-displacment curves for average of penetrations tests with chisel type knife under wet conditions.
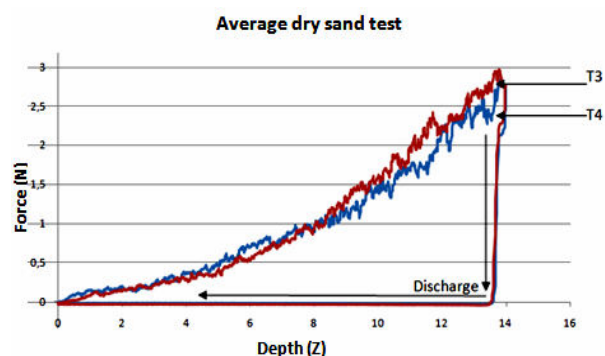
Figure 11. The experimental load-displacement curves for average of penetrations tests with chisel type knife under dry conditions.

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 the 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.
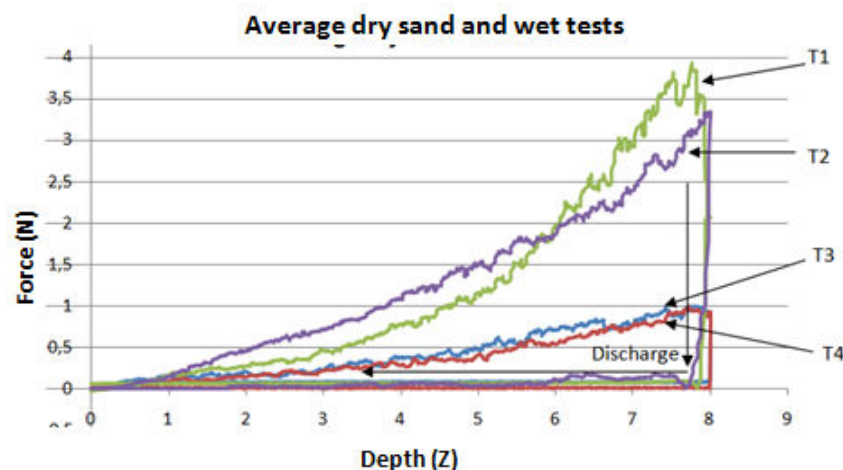

Figure 12. The experimental load-displacement curves for average of penetrations tests with chisel type knife under dry and wet conditions.

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.

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