OPTIMIZATION OF TRIBOLOGICAL PARAMETERS IN THE DESIGN OF ROTARY TILLER BLADES

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Abstract

The argument of this paper is rotary the tiller blade, which undergoes severe surface wear during tillage of agricultural land. The study was conducted by comparing on H-shaped blades, of two different manufacturers, used in rotary tillers, mainly in the fields of Myzeqe, Lushnje. Our tests included the measurement of the abrasive wearing as weight loss of material of each blade to the end of lifecycle - recorded after every 10 hectares cultivated surface in field conditions. We experimented in laboratory the blade wearing through 'pin on disk' test. Another tribological parameter measured in the laboratory was the hardness in Vickers on cutting edge of the blade, before and after wearing. To make the targeted optimization, we initially computed a stressed situation on the blade cutting edge, and then processed through the SOLIDWORKS software, which generates a map of more stressed areas that lead to significant wear. By simulating with geometric parameters of tiller blades, we have sought the situation of stresses with less impact on wearing of tiller blades. This paper is also includes relevant recommendations.

***KEY WORDS**: TILLER BLADE, TRIBO-PAIR, SURFACE WEAR, WEIGHT LOSS, PIN ON DISC.*

1. Introduction and study purpose

In this paper, we focus on efficiency of agricultural machinery used for breaking the soil and preparing the seedbed for the planting of agricultural crops. The main phenomenon that significantly affects the decline of this effectiveness is the wearing of the working parts of these machines. Our study has taken in account the tribological phenomena that occur between the rotary tiller blades and agricultural land [1]. The tiller blades undergo severe surface wear, which means increased costs for agricultural land preparation and therefore food costs [2].

The study conducted by comparing on H-shaped blades, made from two low alloy steel brands of two different manufacturers, used in rotary tillers, MASCHIO H205, mainly in the fields of Myzeqe, Lushnje [3]. We started from a detailed study of the wear as a tribological phenomenon, with the aim of reducing the power requirement by improving the geometry of tiller blade. Thus, the proper design of the rotary tiller blades is essential for efficient operations; by optimizing their geometry, the power required will reduce [4]. At the end of this article are also made recommendations for the selection of appropriate materials for tiller blades.

For coming up here, first analyzed the phenomenon that occurs and then we defined tribological parameters, such as the hardness of the blades, loads on cutting edge of blades, speed and distance prescribed by each tiller blade (distance per working hours) throughout its life cycle, the type and content of the agricultural soil and geometrical parameters of the blade.

2. Tillage and tribological phenomenon on Rotary Tiller blades

Tillage is a process performed to obtain a desirable soil structure for a seedbed. This is a granular structure that allows rapid infiltration and good retention of rainfall, will provide adequate air capacity and exchange within the soil and minimizing resistance to root penetration. Rotary tiller is a tillage machine designed for preparing the land by breaking the soil with the help of rotating blades [2].

***Fig. 1.** MASCIO H205 rotavator with 10 flanges and 60 blades; 1 - rotor, 2 – right blade, 3 – left blade, 4 – flange (on the left); The tiller blade 1 and 2 in study, from two different manufacturers made from two different steels brands, ‘C’ shaped & ‘H’ type [3].*

Our rotary tiller, MASCHIO H205 [3], is a specialized mechanical tool used to plough the land by series of blades ('C' shape, 'H' type) which are used to swirl up the earth (fig. 1). This rotavator is available in the size 2.00 m working width, which is suitable for tractors having their power 30 to 60 hp. The work quality by using rotavator not only depends on the machine performance but also on soil conditions, blade geometry and velocity ratio. It often happens to interfere on the backside of the blade and the uncut soil, which may result in severe soil compaction and high power consumption. This is the main reason to cause vibrations, which are a result of the soil upon the tiller blades. The proper design of the rotary tiller blades is essential for efficient operations [5].

Both blades and tillage constitute a tribologic pair. These blades interacting with soil subjected to impact of soil crust / clods / stone and high friction, which develop high stress areas on blade tip or blade critical edges. Tribological phenomenon that is present throughout tillage and the life span of tiller blade is predicted by wear. Blades are under pulsating loads and subjected to high abrasive wear and fatigue. As this wear, the total cost of agricultural production inflates [6].

Our rotary tiller has 10 flanges with six blades for each flange. Each blade cuts a segment of soil as it removes downward and towards the rear. Because of the high peak torques developed during each cut, it is important to stranger the blades in the different courses, with equal angular displacement between them, so no two blades strike the soil at the same time (Fig.2).

We think that an appropriate geometric shape of the tiller blade will provide easy soil cutting by reducing the maximal loads (their high stress), consequently reducing blade wear. Let us have a look at the experiments and measurements that we have done for determining the blade wear on the field and laboratory, as well as some of the other tribological parameters associated with this phenomenon.

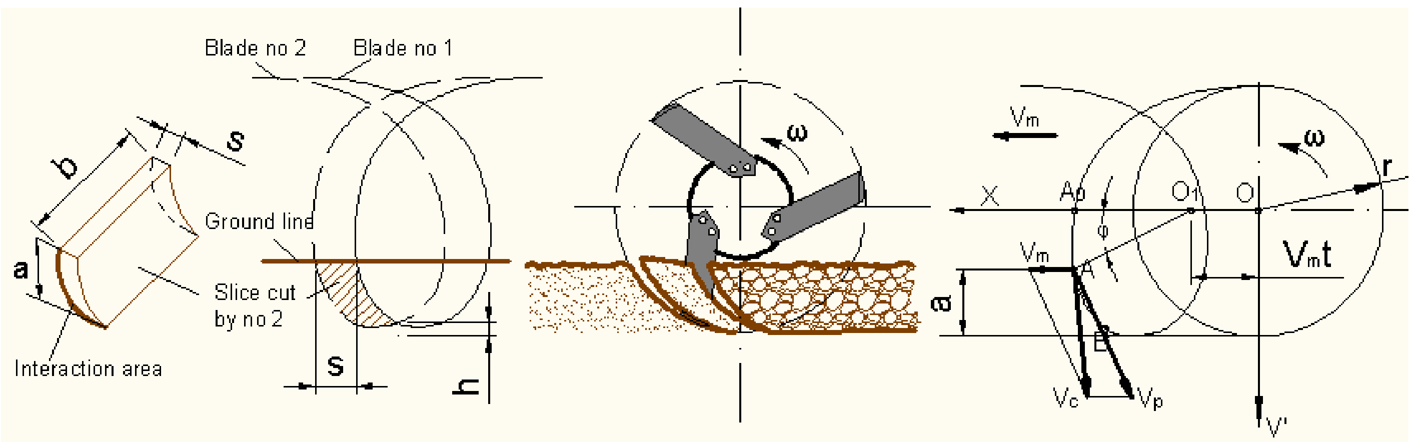

Fig. 2. *Parameters of the rotary tiller blade movement and forming of the slice cut [11]*

3. Testing on ground and Laboratory

3.1. Field test procedure

Based on the available data and feedback from users, it has been found that the blade is worn out after certain hours (100 – 300 hours) field usages depending on the soil conditions. Two are the factors that we have considered: the tillage or digging strikes of blade in soil and the linear distance described by tiller blade throughout their live span. Digging and strikes of tiller blades on soil will cause excessive loads and high stresses that are related with fatigue wear. The second factor related with high friction due to stones, gravel and sand in soil during the tillage and consequently the abrasive wear is also present. The blades undergoing severe surface wear of the tip and cutting edges.

Number of strikes by cutting edge of tiller blade is 8000 strikes / ha [1]. Our field test was measured after tillage of 45 ha; so, there are 360000 strikes of a tiller blade.

The linear distance described from a point of cutting edge of tiller blade when interacts with soil (fig. 2, bold contour), for a slice cut is 20 cm, for 15 cm tillage depth (diameter of rotor is 20 cm and diameter of tip of blade is 50 cm), will be 1600 m/ha and 72000 m per 45 ha.

Let us calculate the wear rate, *w*, for each of tiller blades, 1 and 2 [7], when their loss weight is respectively 95 gr and 158 gr:

$$w = \frac{\text{Volume of material removed from contact surface } (m^3)}{\text{Distance slid (m)}} = \frac{V}{L}\ (m^2) \quad (1)$$

$V_{Blade\ 1} = m/\rho = 1.2\text{x}10^{-5}\text{m}^3$ and $V_{Blade\ 2} = 2\text{x}10^{-5}\text{m}^3$, where specific weight, $\rho = 7900\ \text{kg/m}^3$.

Fig. 3. *Wear tiller blades 1 and 2, after tillage of 45 hectares (on the left) and blade 2 (on the right) as new product that weight 720gr, under it the same blade with full wear at the end of its lifecycle.*

Our tests included the measurement of the wearing as weight loss of material of each blades recorded after every 10 hectares cultivate surface in field conditions after tillage of 45 hectares.

Table 1. Wearing of blades that is defined with loss weight

Hectares / Blades product	10	10	10	10	5
Blade 1 (gr)	21	22.3	20.2	19.5	12
Blade 2 (gr)	40,6	36,5	35,7	33,1	12.1

It is observed a severe wear at the beginning of the life cycle of new blades. The wearing of blade 1 is far less than 2 ones.

3.2. Wear Testing with Pin-on-disk apparatus (G-99)

This test method describes a laboratory procedure for determining the wear of materials during sliding using a pin-on-disk apparatus [8]. Materials were tested in pairs imitating real conditions of tiller blade work mainly in clay soil or heavy loam. Pin is a prismatic specimen with a flat surface on the tip such that it will support the load over its entire cross-section, is positioned perpendicular to the other, usually a flat circular disk. The specimen of pin is taken from tiller blade and disc is an abrasive stone with corundum particles. The pin specimen is pressed against the disk at a specified load usually realized by means of an arm or lever and attached weights [9].

The pin was held against the counter face of a rotating disc with wear track diameter of 60 mm. The pin was loaded against the disc through a dead weight loading system. The wear test for all specimens was conducted under the normal loads of 20N, 40N and a sliding velocity of 2 and 4 m/s.

Wear tests were carried out for a total sliding distance of approximately 3000 m under similar conditions as discussed above. The pin specimens were 43 mm in length and 72 mm^2 and 78 mm^2 in the across section, respectively made from blades 1 and 2 materials.

The wear rate was calculated from the weight loss technique and expressed in terms of wear volume loss per unit sliding distance. The specific wear rates of the materials were obtained by [10]:

$$W = \frac{\Delta w}{L \rho F} \qquad (2)$$

Where W denotes specific wear rates in mm^3/N, Δw is the weight loss measured in grams, L is the sliding distance in meters, ρ, density of the worn material in g/mm^3 and F is the applied load in N.

Table 2. Weight loss of the steel specimens in grams

Weight loss of steel sample of pin							
		Sliding speed, 2 m/s			Sliding speed, 4m/s		
No	Specimen name	Initial weight (gr)	Final weight (gr)	Weight loss (gr)	Initial weight (gr)	Final weight (gr)	Weight loss (gr)
1	Blade 1	35.046	34.242	0.804	34.242	32.425	1.817
2	Blade 2	36.173	34.041	2.132	34.041	30.004	4.037

Results of laboratory tests attest measurements of wear of tiller blades during tillage in field.

3.3. Chemical composition and microstructure observation

It is clear that the severe surface wear is present on rotary tiller blades. We have already defined the types of wear and its wear mechanisms. The occurrence of different types of wear mechanisms may depend upon the chemistry, microstructure and hardness of material. To access which wear mechanism dominates between our two steel grades, let us do the analysis of chemical composition, microscopy and hardness test.

The chemical composition of rotary tiller blades made from low alloy steel given in Table 3, offers a good combination of mechanical properties, which are required to exhibit excellent resistance to fatigue loading and severe wear from high friction, as necessitated by tiller blades during field operation [6].

Table 3. Chemical composition (wt. %) of our tiller blades

	C%	Si%	Mn%	P%	S%	Cr%	Ni%	Mo%
1: **72MnCrB5-2**	0.221	0.252	1.4	0.023	0.0076	0.385	0.173	0.068
2: **33MnCrB5-2**	0.302	0.222	1.39	0.024	0.012	0.424	0.202	0.078
	Al%	Cu%	Co%	Ti%	B%	V%	W%	Pb%
1: **72MnCrB5-2**	0.016	0.265	0.015	0.042	0.0017	0.0075	<0.007	.0012
2: **33MnCrB5-2**	0.017	0.227	0.01	46	0.0018	0.0063	<0.007	<.001

Now we know that the properties of engineering components depend on the structure of material. Microstructures views show clear crystallographic compounds.

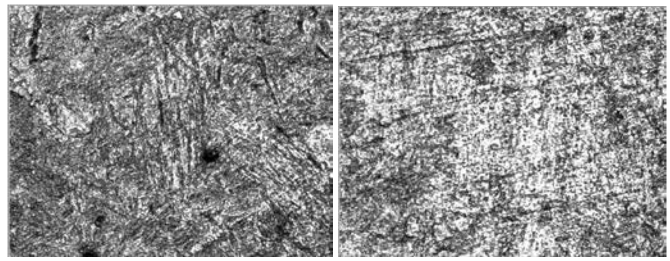

Fig. 4. Microstructural views of new tiller blades 1 (on the left) and 2 (on the right); Samples are taken in cutting edges areas of each blade and corroded with 4% nital, 500 x. Tiller blade 1 has needle and bejnitic structure while the blade 2 has fine granulated structure with chrome carburets.

These materials have high resistance against abrasion and are used for tools that work in high friction. Such is our case study of tiller blades.

3.4. Hardness Testing

Hardness is the most important tribological parameter. In a tribosystem is the soft material that undergoes a severe wear. In our tribo-pair, tiller blade made from low alloy steel and soil, can be thought that blades are many time stronger than soft soil. Nevertheless, it is not so, because there are too many stones, gravel and sand into the soil, which are harder than the steel of blades. Therefore, the blades that undergo a severe wear that often end with breaking, fracture or failure. Here there are shown the results of Vickers Micro-Hardness test, for new (unwearing) and wearing tiller blades. The test load is 10 N or 1 kg.

Table 4. Results in Vickers (HV) measured before and after wearing

Distance from cutting edge		0.5 mm	1.5-2 mm	7-8 mm	15 mm
Blade 1:	Before	368.5	493.6	565	547
	After	540	534	533	539
Blade 2:	Before	533.6	593.3	564.6	530.6
	After	567	600	577	575

These results show a reinforcement of surface in cutting edge blade due to its plastic deformation in the cold, during tillage operation when the blade shocked with the solid material in the soil. Reinforcement is quite obvious on the blade 1, while highest values of hardness encountered on blade 2 (600HV).

4. Design of rotary tiller blades

The design of rotary tiller blades depends on type and number of blades and the working conditions of rotary tiller. In this design, the 'H' type blades are considered for the rotary tiller according to the working conditions presented. The total power of machine, N_C, is distributed between the blades: $N_C=40hp$. Our rotary tiller was designed with the working width of 200 cm and having $i=10$ flanges on the rotor shaft with six blades on each flange. The agricultural land in Myzeqe, Lushnje is between clay soil and heavy loam, non-rocky soil.

4.1. Calculation of forces on the blade

Two major forces are known to act on rotating blade used for tilling or digging operations. Tangential force, P_O, acts at the tip of the blade as shown in Fig. 5, through tangent of blade cutting edge [11]. Soil force, R_T, acts perpendicular to cutting edge of the blade. Soil force for analysis is considered as uniformly distributed load acting along the cutting edge.

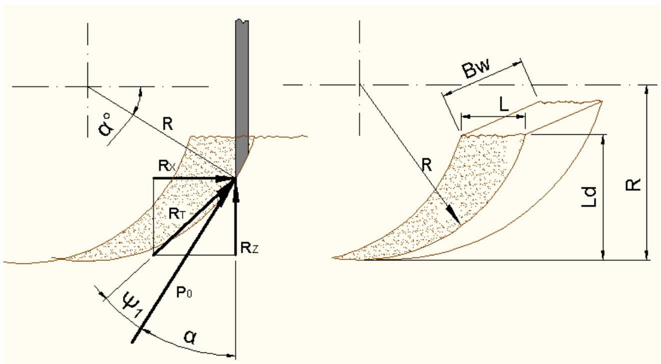

Fig. 5. *Major forces acting on a rotavator blade and dimensions of sliced soil [11]*

The maximum tangential force that occurs at the minimum of blades tangential speed is calculated by following relation (Bernacki et al,):

$$P_o = C_s \frac{75 N_c \eta_c \eta_z}{U_{min}} \quad (3)$$

Where C_s, is the reliability factor; $C_s=1.5$, for non-rocky soils; $N_C=40hp$; η_c, is traction efficiency; $\eta_c=0.9$, because the directions of tractor forward speed and the rotational speed of rotor shaft are the same. η_z is coefficient of reservation of power taken 0.7-0.8, $\eta_z=0.75$; u_{min} is minimum peripheral velocity: $u_{min}=v\lambda$, λ=u/v; u, tangential speed of blades (m/s). v, forward speed (m/s). Forward speed is dependent to the tangential speed of blades (that is function of rotational speed of rotor, n) and the length of sliced soil, L.

In our calculations [1, 11, 12], $v=0.6$ m/s, $\lambda=2.13$, $L=36.85$ cm, $R=25$ cm, conventional rotor radius, $Z=3$, number of blades on each side of the rotor flanges; $\lambda_{min}=1.42$ and $u_{min}=0.85m/s$.

$$P_o = C_s \frac{75 N_c \eta_c \eta_z}{U_{min}} = 1.5 \frac{75x40x0.9x0.75}{0.85} = \mathbf{2382} kg$$

The soil force acting on the sharpened edge of each blade, R_T, is calculated:

$$R_T = \frac{P_O x C_p}{i Z_e n_e} = \frac{2382x1.5}{10x6x6/60} = \mathbf{595.5}\ kg \quad (4)$$

Number, n_e is obtained through division of the number of blades which action jointly on the soil into the total number of blades; $C_p=1.5$, coefficient of tangential force;

The main forces on blade are the maximum tangential force, P_o = $2382kg$ = $23360N$ and the soil force, R_T = $595.5kg$ = $5840N$.

4.2. Optimal design of blades by simulating with SolidWorks

Proper design of tiller blades is necessary in order to increase their working lifetime and reduce the farming costs. High rate of wear is the phenomenon, which will reduce the service life. Seeing under this prism, the blade geometry shape is directly related to the phenomenon but also to the quality of tillage. Often the farmers complain for bad quality of land preparation. That is true. Therefore, we think that an appropriate geometric shape of the tiller blade will provide easy soil cutting by reducing the maximal loads (their high stress), consequently reducing blade wear. Initially we simulated the maximum tangential force, P_o and soil force, R_T on the blade (fig.7). This figure shows comparison of results with FEM: stresses and deformations/displacements caused from complex loading [13].

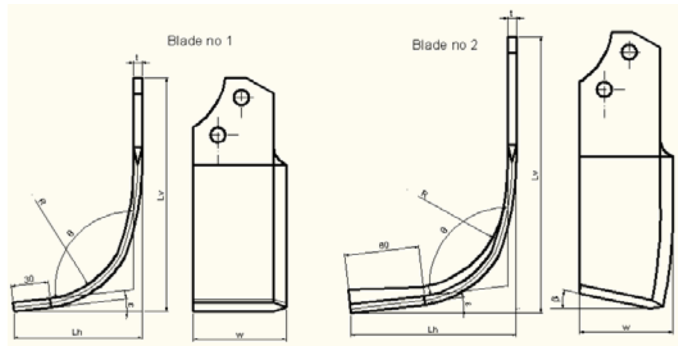

Fig. 6. *Blade schematic with designed parameters (values in Tab.5)*

Table 5. Parameters of different blades designed for the study

Parameters	Notations	Values	
		Blade 1	Blade 2
w	Blade span, mm	75	75
L_v	Effective vertical length, mm	188	222
L_h	Blade cutting width, mm	103	133
R	Curvature between L_v - L_h, mm	85	80
θ	Blade angle, degree	96°	97°
β	Clearance angle, degree	3°	12°
t	Blade thickness, mm	7	7
ε	Bending angle, degree	6°	7°

To do an optimizing of the blade design have to consider that blade parameters are functions of operating parameters, soil parameters and tool parameters. Two are geometric parameters, thickness t and curvature R that optimized tiller blades on plane 6, where software found the situation of stresses with less impact on wearing of tiller blades.

Table 5. Tribological parameters after optimizing of t and R.

Tribological parameters	Blades	Original	Optimal	Plane 6
Blade thickness (mm)	1	7	5.6	8.5
	2	7	6.2	8
Curvature R, (mm)	1	85	75	85
	2	80	70	90
Von Misses stresses (N/m^2)	1	11.13e+009	12.33e+009	10.81+e009
	2	6.887+e009	7.204e+009	6.573+e009
Displacements (mm)	1	27.67	32.45	18.08
	2	21.7171	24.55	19.5

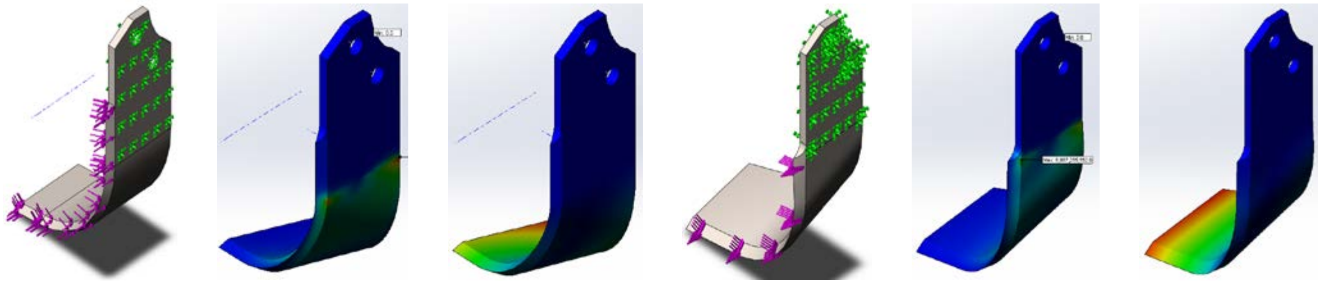

Fig. 7. *Comparison of result between blade 1 (on the right) and 2 (on the right): loading, stresses and displacements*

5. Results and Recommendations

- The results of testing on ground and laboratory show that tillage is a process that is realized with the help of rotary blades, which undergo a very large wear of its cutting edge. There are two forms of wear in tiller blades, abrasive and fatigue; dominate abrasive wear. This wear reaches approximately 1/4 of the initial weight up to the end of life. The results of wearing was determined by means of method of material weight loss.

- Chemical analysis determined the grades of steel: 72MnCrB5-2 and 33MnCrB5-2. While the microstructure observation shows respectively its needle and bejnitic structure for blade 1 and fine granulated structure with chrome carbures for blade 2. These materials have high resistance against abrasion and are used for tools that work in high friction. Presence of boron, B gives a significant increase in tempering/hardening of low alloy steels, providing a better behavior against wear. Relatively low carbon content (less than 0.35%) of these steels after quenching causes them not to reach too high hardness (less brittleness), but provides a combination of moderately high reinforcement with good tenacity and high resistance to abrasive wear.

- Results of hardness testing show that this property increases after a working period. It is a reinforcement of surface in cutting edge blade due to its plastic deformation in the cold, during tillage operation when the blade is shocked with the solid material in the soil. The reinforcement is obvious on the blade 1 and 2, while highest values of hardness are encountered on blade 2 (600HV). Experience confirms that blades with very strong surface are brittleness and come out of use very quickly or accidentally, as is the case of the blade 2.

- Our recommendation in this case related to the preparation of tiller blades is that they should be strong on the surface but plastic inside so they will face better the shocking with solid materials into the soil without failure.

- Our calculation of forces in blades show a complex stresses situations caused from tangential force acting at the tip of the blade (P_o*=2382kg*) and soil force acting perpendicular to the cutting edge of blade (R_T*=595.5kg*). Results generated from SolidWorks show a less stresses situation and deformations on blade 2 than on blade 1.

Conclusions

CAD method is an effective tool for the development of blade as this the main critical parts of a rotavator. It always exist the tribologic phenomenon, which often happens in these parts that encourages us to look for ways to reduce its impact on the tiller blade. CAD combined with finite elements method in SolidWorks are useful tools for analyzing stresses and deformations in design of complex geometries. Less wear of blades means less power of tractor and higher effectivity of preparation this agricultural land. The power required can be lowered by optimizing the blade and minimizing stresses. Above analysis reveals, that blade 1 undergoes high surface stresses, which reinforce their surface and make it more resistant against wear. Field study & hardness test confirmed these results.

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