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Theoretical aspects on the abrasive wear of farming tools

Aspectos teóricos sobre el desgaste abrasivo de los aperos de labranza

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ABSTRACT

The damages suffered by the farming tools have a negative influence on the productive process and they represent considerable economic losses for any enterprise. That is the reason for which this paper presents the outcomes of an updated bibliographical revision related to the abrasive wear of farming tools; which is compared with the results of the experiments carried out by Sánchez Iznaga (2015) in regard to this kind of wear within his doctoral research and in the Cuban context. The research approaches those aspects related to the type of soils where the abrasive wear of farming tools occurs frequently, the main causes of this wear occurrence, the equipment used to determine the damages which it causes, and the most useful methods in simulating it; as well as the conclusions achieved by Sánchez Iznaga (2015) of every aspect mentioned earlier in the Cuban context and taking into account the results obtained in his experiments.

Keywords:

Abrasive wear, farming tools, simulating methods.

RESUMEN

Los daños que sufren los instrumentos de labranza tienen una influencia negativa en el proceso productivo y representan daños económicos cuantiosos para cualquier empresa. Es por ello que en el presente trabajo se presenta el resultado de una revisión bibliográfica actualizada y relacionada con el tema antes mencionado; la cual es comparada con los resultados de los experimentos llevados a cabo por Sánchez Iznaga (2015) como parte de su investigación doctoral en el contexto cubano. La investigación aborda los aspectos relacionados con los tipos de suelos donde se produce con mayor frecuencia el desgaste abrasivo de los aperos de labranza, las principales causas que lo originan, el equipamiento utilizado en la determinación de los daños que el desgaste ocasiona y los métodos más utilizados en la simulación de este fenómeno; así como las conclusiones a las cuales arriba Sánchez Iznaga (2015) en cuanto a los elementos citados anteriormente en el contexto cubano.

Palabras clave:

Desgaste abrasivo, aperos de labranza, métodos de simulación.

INTRODUCTION

On a global scale, the development of agriculture has been materialized by several factors, within which stand out the creation and modification of farming tools based on designs that guarantee a higher labor's quality, lower levels of energy consumption and soil damage, being this latter which causes a declining of soils' fertility and lower levels of agricultural produce.

In Cuba, those soils that are classified as Ferralítico Amarillento according to the new version of the Soil Genetic Classification in Cuba and Ultrasol according to the Soil Taxonomy stated by the United States Department of Agriculture (United States, 2010) and the International classification of soils (United States, 1988) are one of the most important of the country.

The soils that are mentioned above are those used to plant tobacco, vegetables, grains, and tubers as well as for the animal breeding such as livestock. They are also widely spread around the country and occupy a territorial expansion of about 645 448.50 ha. This kind of lands are considered highly frictional for the farming tools, this condition is caused by their granular composition in which are common the sand particles (up to 87%) and the particles of quartz (SiO_2/F_2O_3) which make the 10 to 15% of their structure (Sánchez Iznaga, 2015). These particles' hardness provokes the abrasive wear of the farming tools which means a rising energy consumption and costs of all harvest activities (Herrera, et al., 2010).

According to what it has been said so far, the abrasive wear of farming tools has been studied by many researchers, taking into account that it has caused, internationally and nationally, economic losses of about 15 000 000 000 of dollars in countries with high development in mechanization (Ulusoy, 1981; Martínez & Rodríguez, 1985; Kushwaha & Chi, 1991; Fielke, et al., 1993; Bayhan, 2006; Agodzo, et al., 2007; & Crowe, et al., 2007).

In order to determine the degree of wear, it has been traditionally used some analytical and experimental methods, being the latter ones the most used (Fielke, et al., 1993; Martínez & Rodríguez, 1987, 1988; Kushwaha & Chi, 1991; Bayhan, 2006; Crowe, et al., 2007; Prins, 2007; Nalbant & Palali, 2009; Graff, 2010; Sánchez Iznaga, et al., 2010 & Sánchez Iznaga, 2015).

At the present time, diverse numeric methods are being used, which have some advantages with regards to the previous ones, and the chance of success they have implicit is due to the possibility they bring to forecast the occurrence of the abrasive wear in farming tools. Within the above-mentioned methods, the method of discrete elements is the one which has been mostly applied because it considers the soil as a discontinuous environment, being this reason the one which gets it closer to real life (Recarey, et al., 2001).

In order to study the abrasive wear, many researches have focused on studying its magnitude in working tools, determining the wear by impact caused to excavation devices like the ones used in mines; which differ from the ones used for farming in their form, geometry, the surface of the ground where they are used and the mechanical characteristics of the soil (Recarey, et al., 2001; Burrel, 2003; Gutiérrez & Fuentes, 2007 & Graff, 2010).

So, taking into account what it has been said previously, this paper has as its main scope to carry out a theoretical revision on the aspects related to the abrasive wear of the farming tools and to compare them with the experimental outcomes achieved by Sánchez Iznaga (2015), in his doctoral research within the Cuban context.

METHODS

Theoretical methods used:

» Historical-logical method: to approach, in a historical and logical way, the background of the abrasive wear in farming tools, methods which are used to determine it and the results achieved in the simulation of this phenomenon, in the world and in Cuba.

» Analytical-synthetic method: to analyze and synthesize the main results achieved by simulating the subject studied, its characteristics of occurrence, the most important methods used to determine it and to conclude about the fact mentioned above.

» Inductive-deductive method: to make generalizations about the abrasive wear of farming tools which is used during the development of the research paper.

» Systemic method: to guide the development of the research toward the achievement of the objectives proposed.

The following procedures and techniques will be used:

» Simulation: to simulate through experiments the abrasive wear of farming tools, taking into account the criteria of different authors and to conclude about the study object.

Empirical methods:

» Observation: used to obtain evidences form the experiments carried out which allows to compare the praxis with the theoretical principles related to the study object.

» Documents revision: to classify and order all the information contained in the bibliographical sources consulted.

RESULTS AND DISCUSSION

Types of abrasive wear in farming tools

The characteristics of the operations in which the farming tools are used cause the abrasive wear in this equipments as it is shown in figure 1. Moreover, the long periods of time these devices are stored in adverse conditions favor the oxidative-corrosive process which provokes the corrosive wear, being this one the commonest type of wear in the farming tools, although the abrasive wear is the most destructive because it brings on important material losses in a long-term period of time.

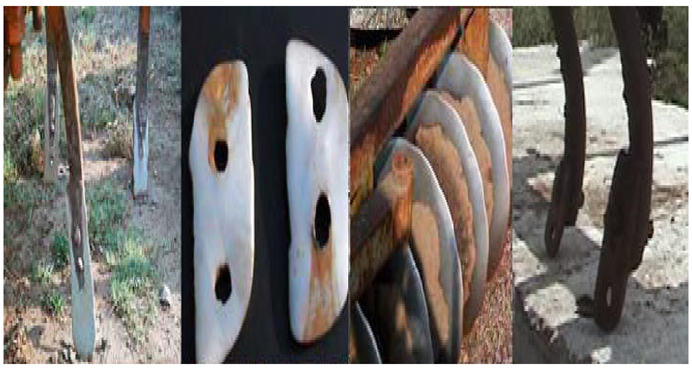

Figure 1. Farming tools abrasive wear
Source: Adapted from Sánchez Iznaga (2015).

Martínez & Rodríguez (1988); Ochoa (2004); Herrera, et al. (2010)**,** argue that within the diverse factors that influence on the farming tools are the following ones: the environment characteristics (humidity, corrosive atmosphere, and presence of abrasive particles), characteristics of the materials they are in contact with (chemical composition, hardness, dimension, geometry, superficial wrinkle, and microstructure), use or operational conditions (load carried, speed, temperature, types of movements, type of friction, run of the friction, working time, and working depth), and organizational and human factors.

Economic losses and problems associated to the abrasive wear

As it has been stated by Ulusoy (1981); Kushwaha & Chi (1991); Fielke, et al., (1993); Bayhan (2006); Agodzo, et al., (2007); Crowe, et al. (2007), one of the reasons that has been present in many studies of the abrasive wear is the one related to the economic losses that it brings into being in every country. This argument is also supported by national researchers such as Martínez & Rodríguez (1985); Sánchez Iznaga, et al. (2010) & Sánchez Iznaga (2015).

Many researchers from different parts of the world who have study the abrasive wear have noticed that this phenomenon caused and have caused serious repercussions in the majority of the mechanical processes that take place in agricultural activities. Its occurrence has made important economic losses happen which summed yearly a quantity of 940 000 000 of American dollars in Canada (Kushwaha & Chi, 1991); in Australia, as Riley, et al. (1990), pointed out, the annual losses were of about 20 000 000 of American dollars; Bayhan (2006), considers that in Turkey, the losses caused were about 44 000 000 of American dollars. More recently, Sánchez Iznaga (2015)**,** argues that in the United States and in Cuba the economic loss is yearly of 15 000 000 000 and 200 000 American dollars respectively.

In spite of the time passed by, Casal (1997)**,** argues about the repercussion of the abrasive wear, facts that the authors of the present paper consider are the same nowadays. Casal (1997)**,** notes that the main cause for the 85% of the substitution of the agricultural machinery elements is the abrasive wear in Cuba. In the other hand, it causes some other problems, such as: the loss of the useful energy required for the soil labors due to the friction generated during the interaction of the structural elements of the laboring tools with the soil, the increase of oil consumption and of the operational expenses of the farming machinery and tools because of the raising of the useless resistances produced by friction and the waste of time originated by increase of the displacement and of the failure frequency. These aspects will be discussed in the next section.

Loss of useful energy required in farming

According to the point of view of Herrera, et al. (2010), just a 54% of the total work done with the farming tools is utilized due to the loss of a 46% of the useful work. This author considers that this loss is produced by the useless resistances which occurs during the friction of the soil with the structural elements of the working tools; adding that the 25% of the total lost work is on account of the friction between the soil and the grid, a 17% is lost because of the friction between the soil particles and the working tools' frame and the remaining 4% is lost as a result of the plow resistance to roll. This work loss brings on a useful energy loss which produces an increase in consumption rates of oil and operational expenses.

Hernández (2006)**,** notes that the useful energy consumed in farming also depends on other factors, such as the type of soil, the shape of the working tool, the forward movement speed of the latter and the depth which is performed during the farming activities like drawing over soil to turn it over and cutting furrows in preparation for the planting.

The energy consumed during the farming activities is conditioned mainly by the type of soil and its state after the primary labor activities. Those soils whose clayey content is over the 30 to 35% of their total composition require more energy than the others. In the systems of minimum labor, the primary activity carried out with a vertical farming tool allows to decrease a 30% the energy consumption.

It should be taken into account that the farming activities are those which consume the major quantity of energy and consequently those whose oil consumption is the highest of all. Approaching this subject, Hernández (2006), argues that the energetic efficiency involved in displacing and operating some farming tool is very low and it does not exceed a 20% value. The main cause for the occurrence the latter is due to that the energetic transformation of the engine reaches, in the best case scenario, a 40% efficiency value and the traction efficiency of a tractor does not exceed a 50% value. What it has just mentioned means that every 100 liters used are utilized 20 liters. It should be added to the undermentioned facts, the energy expense caused by the friction and the metal-soil adherence when operating the farming tools.

On the other hand, Burrel (2003), analyzes the increase of wasted times and points out that the delays in farming activities caused by adjustments and unexpected failures (like those which occur because of the farming tools wear) may become critical by increasing the manufacturing costs and the decreasing of the labor activities' quality.

From what it has been analyzed so far, the authors of this paper considers that the farming tools' wear is not the only but one of the most important causes which influence negatively in both the economic performance and quality of the agricultural produce in any entity dedicated to this kind of activity, so those who lead this kind of organizations have to keep in mind the importance of preventing it by assessing it properly on time. That's the main reason for which the next section of this paper will be dedicated to analyze the assessing methods of the abrasive wear of farming tools.

Methods of assessing the abrasive wear in farming tools

As it has been stated by Barajas (1995), any wear could be quantified by measuring the lost material from tools caused by their interaction with the soil and it may be expressed in mass, weight, volume, surface or length; although Burrel (2003) mentions that the wear could also be determined by knowing the wear speed of the material the farming tools are made of.

Some authors like Fielke, et al. (1993); Martínez & Rodríguez (1987, 1988); Chi & Kushwaha (1991); Bayhan (2006); Graff, et al. (2007); Prins (2007); Nalbant & Palali (2009); Graff (2010); Sánchez, et al. (2010); y Sánchez Iznaga (2015), that in order to determine the above-mentioned wear, it has traditionally used analytical and experimental methods, being the latter ones the most used.

On this subject Recarey, et al. (2001); Burrel (2003); Gutiérrez & Fuentes (2007); Graff (2010); Sánchez Iznaga (2015), have noticed that some other methods have been developed, mentioning the numeric methods.

As Álvarez (2000), notices, the analytical methods are those which use mathematical equations to determine the quantitative wear values in different elements of machines that are used in different conditions of friction, like the case of the farming tools. Through this method the values obtained allows incorporating the friction effect, the wear and the influence of other factors related to its appearance to the design calculations, but it has not been developed an equation through which the absolute values of the wear be determined nevertheless.

The author cited above also points that the experimental methods use techniques associated to certain equipment developed in accordance with the wear type which appears. The experimentation takes place in a laboratory (controlled conditions) or during the operation of these tools. The studies of the wear in a laboratory have been related to the wear of the mechanical elements used in the industry, although they have been covered other type of elements, such as the farming tools.

The major inconvenience of assays in laboratory conditions is that most of the time the abrasive nature is different from the characteristics of the soil and that the work regimes are also different from those in which these tools are operated, which causes that the mass and volume loss are not comparable in both conditions, being the main reason for which the wear models differ considerably.

To determine the abrasive wear in a laboratory, the pin on disk method has been widely applied. In order to carry out the test, two test tubes made of the material to be analyzed are required. The first one is a pin whose size is too reduced and which is placed perpendicularly in regards of the other piece that it is usually a circular disk. The test machine makes the pin or the disk to rotate, causing a wear path in the disk. The disk could be positioned vertically or horizontally, although the disk position has a direct influence on the wear resulted from the experiment.

The test carried out by using the disk ASTM consists of throwing sand between the disk and the test tube, causing the latter one to wear out. Within the main machines built to determine the abrasive wear are the following ones:

Machine (MA-1) which facilitates the study of the resistance to the abrasive wear of materials and pieces under an abrasive environment and according the stated norms for this kind of test.

Machine of revolution friction (MFR-03), which allows characterizing the friction and the wear of tribological pairs with metallic and nonmetallic recovering.

Machine for the study of the wear of flexible elements (MD-02) through which the simulation and study of the wear mechanism in flexible elements is possible.

Prins (2007), making reference to the equipments designed to develop wear assays in operational conditions, points out that this environment produces some difficulties when controlling the variability of the experiment conditions, so rotational banks for testing have been developed which allows the attainment of such tests in controlled conditions.

Among the numeric methods used to determine the farming tools' wear are: the finite elements method, the outline elements method, and the method of discrete or different elements.

Some of the features that should be taken into account when using the previous mentioned methods are the soil parameters and the interface soil-farming tool.

The microstructural soil parameters employed have been related to the model implemented, the code or software in which the numerical solution of the models will be found out. In this sense, the most used parameters are: the Young module (E), Poisson coefficient (ν), the Coulomb coefficient of friction or interparticles friction (and the microcohesion of soil (C´).

As stated by Kozicki & Tejchman (2011), the Young module (E) and the Poisson coefficient (ν) are input parameters used in the method of discrete or different elements, because they are related to the normal rigidity (k) and the coefficient $\frac{k}{k}$ which characterized the contact model between particles.

Recarey, et al. (2001); Burrel (2003); Asaf, Rubinstein & Shmulevich (2006), notice that the two above-mentioned parameters have been estimated through the simulation of assays in sandy soils, obtaining good relations between the simulation results and the experimental ones.

In regard to the Coulomb coefficient of friction or interparticles friction, Recarey, et al. (2001); y Burrel (2003), stand out on their use to model the cohesion loss or breaking of the tool material at a microstructural level.

Among the methods analyzed previously, the method of discrete or different elements is of a great use nowadays in solving engineering problems within which is the farming tools' wear, being this one the reason for which the next section will be dedicated to analyze this issue.

Numeric simulations of the farming tools' wear through the method of discrete or different elements

It has been developed 2-D and 3-D models to simulate the farming tools' wear through the method of discrete elements (see figure 2). The characteristics of these models have been in function of the scope set for the simulation as well as the geometry of farming tools.

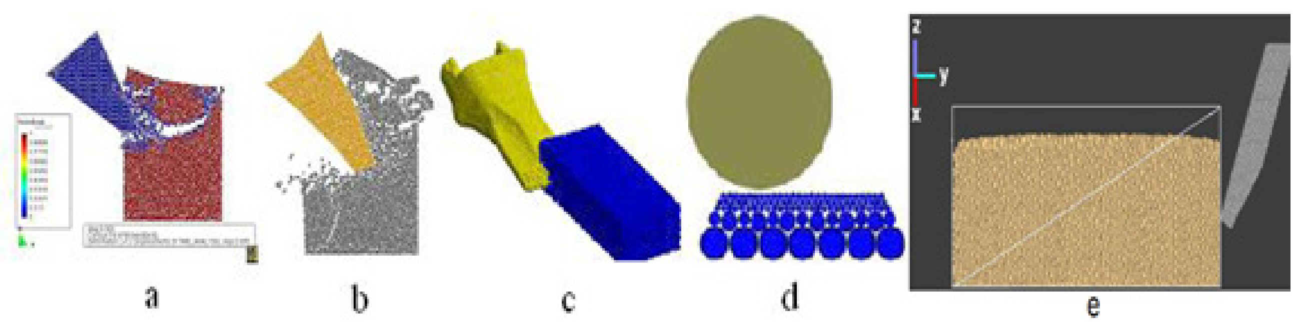

Figure 2. Models for simulating farming tools' wear.
Source: Adapted from a) and b) Recarey, et al. (2001).
c) Burrel (2003) d) Graff (2010) and e) Sánchez Iznaga (2015).

Generally, Recarey, et al. (2001); Burrel (2003); Sánchez Iznaga (2015), carry out models by using a slab of rectangular soil which is worked with a farming tool. Such slabs are generated taking into account a preliminary drawing developed in advance in 2-D or 3-D which is filled by particles of a standard of a different size. The preferred size of particles used in the simulation varies from 5,2x10[4] to 7 mm, according to the particular characteristics of particles used in each model.

In every case are used spherical particles because as it has been stated by Kozicki & Tejchman (2011), these particles produce good results in this kind of experiment, adding that these kind of particles contribute to reduce considerably the calculation time during simulation.

Another of the methods that are analyzed in this paper are those related to the quantification of the mass loss, which will be described consecutively.

Recarey, et al. (2001), develop a model in 2-D with the scope of determining the resilience to the abrasive wear of a farming tool during an excavation process of a sandstone whose mechanic behavior is different from soil. During experimenting, the author above-mentioned took into account the effect of temperature on the occurrence of wear, including this parameter to the Archard Law. The loss magnitude was determined by integrating the wear occurred through time in every particle which was part of the external surface of the excavation tool.

When the magnitude of the mass loss reached the particle size, it is considered it as not being part of the tool due to it provokes a geometry variance. The procedure described above was also used by Burrel (2003), in different kinds of materials.

During the experiment, it was taken into account that the wear ratio is proportional to the pressure in contact (p_n) and to the glide (v_t). This ratio is calculated through the following mathematical expression:

$$w = k\frac{P_n \upsilon_t}{H}$$

Where,

H: Measure of hardness of contact surface

M: Non-dimensional parameter

The procedure used to determine the wear is described as follows:

Integration of the wear:

The wear is integrated, through time, to all particles contained in the external surface of the excavation tool.

Making equal the size of particles and wear:

Once the size of particles is equal to the size of the wear, it is considered that the particle is not part of the tool, so the tool geometry is modified through time. This situation has been implemented taking into account the way it really occurs.

Wear calculation:

The wear was calculated through the following expression:

$$w = \bar{w}\,dt$$

Gutiérrez & Fuentes (2007), simulate the wear of a flat surface under the impact of lifters of a grinder used in mining. In this experiment, the procedure applied to determine the continuous wear took place under the condition that when the wear volume reached the particle size, the latter lost its cohesion to the rest of the particles and abandoned the geometric dominion under study.

To determine the volume loss of the worn-up material was used the principles of Archard Law, which was applied in function to the normal charge that operates on the worn-up surface, the glide distance of particles, the material hardness, and the wear coefficient.

Graff, et al. (2010), simulated the abrasive wear of cylindrical aluminum and steel bars, and in order of quantifying such wear within the model, this author used the Archard Law, which was described in function of the work speed, the normal charge applied to the tool surface, and the material hardness. The wear was calculated through the expression shown as follows:

$$w = \frac{Fv}{H}$$

Where,

W: Wear rate

F: Applied load

v: Relative speed

H: Material hardness

Sánchez Iznaga (2015), simulated the abrasive wear of farming tools in steel soils. This author to quantify the mass loss took into account the resultant strength of soil particles over the particles of the farming tool. The procedure applied by this author is described below:

When the resultant strength on the tool particle exceeds the limit of the strength, during the interaction among particles of the farming tool B and those of the soil A, the radius and the mass of the particle will be zero, considering the particle was removed from the tool (see figure 3). What it has been explained previously provokes that the tool geometry modifies through its use, which is similar to what occur in farming process.

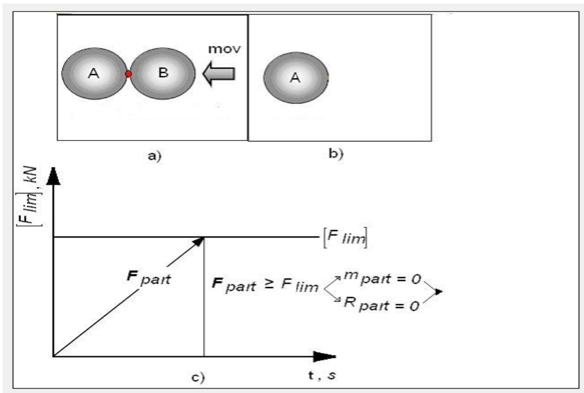

Figure 3. Simulation of the abrasive wear of farming tools in Cuban context.

Source: experiment carried out by Sánchez Iznaga (2015).

This experiment was carried out by using as input data, the Young module of the gage material and the soil cohesion. The procedure to calibrate the resultant strength on tool particles was carried out by using a virtual model similar to the one used in the wear assays, with the difference that the farming tool was represented as a particle on which was measured the magnitude of the resultant strength or the resistance performed by the soil on the farming tool which is represented in Y-axis (see figure 4).

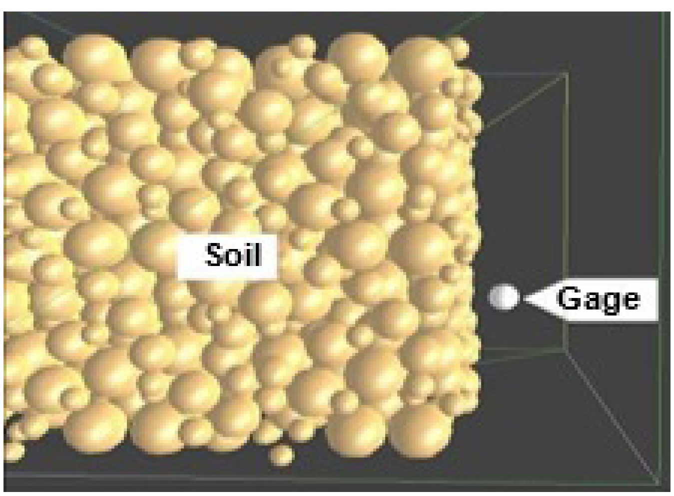

Figure 4. Determination of the magnitude of the resultant strength

Source: experiment carried out by Sánchez Iznaga (2015).

The calculation of the proportion of the mass loss was made by its integral function whose result is the produced mass which expressed by the following expression:

$$P_{masa} = \int P^{`}_{masa}\, dt$$

Where,

$P^{`}_{masa}$: Proportion of the mass loss

The application of the Archard Law and the temperature effect to determine the wear model in the researches carried out by Recarey, et al. (2001); Burrel (2003), has as main disadvantage that model programming process requires the implementation of a thermo-mechanic mechanism as well as the temperature effect over the wear which complicate the programming process.

The advantage of Sánchez Iznaga (2015) model with respect to the others presented is because of its easiness when applying it.

The reason for which Sánchez Iznaga (2015) does not take into account that the temperature effect is that this author tested out through laboratory assays and in operating situations that the temperature values did not exceed 2ºC, which represents the 0,27% of the temperature transformation value of the steel (723ºC).

On the other hand, Recarey, et al. (2001); y Burrel (2003), took into account the temperature values due to that during the stone cut in mining excavation high values of temperatures are registered.

CONCLUSIONS

The experiments carried out by Sánchez Iznaga (2015), in comparison with the theoretical approaches about the study object, allow the authors of this paper to achieve to the following conclusions which can be apply to the Cuban farming processes in order to avoid the degree of occurrence of abrasive wear of farming tools or in its case to calculate the damages caused to such tools:

» The Ultrasol soils are highly frictional for the faming tools due to their sand and quartz content in Cuba; being abrasive wear the most destructive wear for farming tools, taking into account that it has caused important losses of useful energy, an increased oil consumption, waste of time due to the increase of substitutions and the failure frequency, and the occurrence of important economic.

» The most used methods to determine the abrasive wear are the analytical methods, the experimental methods and the numeric ones, being the latter which has been mainly used because it allows predicting such wear.

» Rotational banks are the widely used equipments to determine experimentally the abrasive wear in farming tools, being used by Sánchez Iznaga (2015) because of its advantage of being able to use in controlled conditions.

» The method of discrete elements is the most adequate method to simulate the abrasive wear of farming tools because it offers the possibility to apply the discontinuing theory by representing the individual loss of particles during the occurrence of the abrasive wear of farming tools and trying the soil as a granular material.

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