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Saeed Mehrang Marani
University of Mohaghegh Ardabili, Iran, mehrangsaeed@gmail.com

Gholamhossein Shahgholi
University of Mohaghegh Ardabili, Iran, gshahgoli@yahoo.com

Saeed Kanoon Marani
University of Mohaghegh Ardabili, Iran, kanoon_sa@gmail.com

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INVESTIGATING NANO-COATED SURFACES IN IMPROVEMENT WEAR RESISTANCE OF TILLAGE TOOLS

Saeed Mehrang Marani[1], Gholamhossein Shahgholi[2*], Saeed Kanoon Marani[3]

[1, 3] Graduate student, University of Mohaghegh Ardabili, Department of Biosystem Engineering, Iran
mehrangsaeed@gmail.com , kanoon_sa@gmail.com

[2] Associate Professor, University of Mohaghegh Ardabili, Department of Biosystem Engineering, Iran
gshahgoli@yahoo.com

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دراسة جدوى للتطبيق المباشر لعائلتي ديب وجيورمال الأرض الجافة للتسخين في مباني قرية مويل

ملخص

تتمتع الشفرة في عملية الحراثة بأكبر قدر من التفاعل مع جزيئات التربة. إنه يسبب البلى لهذه القطعة ويقلل من عمرها المتوقع. يعتبر ارتداء أدوات الحراثة ذا أهمية كبيرة للمزارعين من حيث الجوانب الاقتصادية ، وعمليات خفض جودة الحرث ، وزيادة استهلاك الطاقة. تهدف هذه الدراسة إلى دراسة ارتداء خمس مواد بما في ذلك صفيحة st37 من الصلب (SST37) ، والصلب المجلفن (GAS) ، والألياف الزجاجية (GFRP) ، واثنان من الطلاء (أي نيتريد التيتانيوم نانويد (nano–TiN) وكربيد التنتالوم) (نانو– TaC)) عن طريق الاخرق في وسط البلازما للطبقة على الفولاذ التقليدي. تم اختبار هذه القطع في ثلاثة أنواع من قوام التربة الخفيفة والمتوسطة والثقيلة. لتقييم ارتداء الأدوات ، تم تطوير فول الصويا الدوار. تم تقييم مستوى تشغيل الشفرات في ثلاث خطوات من 500 متر وما مجموعه 1500 متر مع معيار لانقاص الوزن بسبب التدهور في تقييم العمليات المختبرية. كان هناك فرق كبير بين العلاجات المختلفة. النقطة المهمة في هذا البحث هي أن الشفرات المطلية بالنانو ، بفضل خصائصها الفائقة والأسطح الملساء ، تتمتع بأفضل أداء للتآكل. تبلغ مقاومة التآكل حوالي 7 أضعاف مقاومة الفولاذ المطلي ، 5.5 مرة من الفولاذ المجلفن. أظهرت الألياف الزجاجية مع ألياف البوليمر المقواة أداء جيدًا ضد الصلب العادي والمجلفن ضد التآكل.

Abstract

The blade in the tillage operation has the most interaction with soil particles. It causes the wear and tear of this piece and reduces its expected life span. Tillage tool wear is of great importance to farmers in terms of economic aspects, reduced quality tillage operations, and increased power consumption. The aim of this study is to investigate wearing of five materials including st37 steel (SST37) plate, galvanized steel (GAS), and fiberglass (GFRP), and two coatings (i.e., titanium nano-nitride (nano-TiN) and tantalum carbide (nano-TaC)) by sputtering in the plasma medium of the layer based on conventional steel. These pieces were tested in three types of light, medium, and heavy soil textures. To assess tool wear, a rotating soilbin was developed. The level of operation of the blades was evaluated in three steps of 500 m and a total of 1500 m with a benchmark of weight loss due to deterioration in the assessment of laboratory operations. There was a significant difference between different treatments. The important point of this research is that the nano-coated blades, owing to their superior properties and the smooth surfaces, showed the least wear. Their abrasion resistance is about 7 times that of the uncoated steel, 5.5 times that of galvanized steel. Fiberglass with reinforced polymer fibers showed a good performance against ordinary and galvanized steel against abrasion.

Keywords: Wear, Nano coating, Tillage tool.

1. INTRODUCTION

Reducing the cost of agricultural products requires extensive studies to improve the efficiency of agricultural operations. Increasing productivity, improving energy efficiency, and reducing production costs can help researchers achieve the goals of a higher, cheaper, and better food supply. Abrasion due to soil roughness is one of the reasons for the destruction of a machinery material, which imposes huge costs in the agricultural industry. It has been reported that half the damage during the tillage operations is due to their involvement with the soil (Davis, 2001). Due to the porous structure of the soil, when the soil mass is pulled onto the tool, it is roughened, leading to an accelerated wear process. Soil texture, soil compaction, and soil moisture can be identified as three main factors which influencing tillage tools erosion. Soil texture is controlled by the soil particle size and its shape. Studies have shown that increasing the diameter of soil aggregates is effective in increasing the wear level. Compaction of soil is another factor affecting the tillage tool abrasion. As harder soils require more force to break, according to the practice of action and reaction force, more pressure is applied to the surface of the tillage, leading to the wear increase (McKeys, 1985). The moisture content has a dual behavioral effect on the amount of abrasion. Increasing moisture to a certain extent causes more continuity in the soil and thus increased pressure of the soil fractures. This pressure rise, which is transferred to the surface of the blade, increases the abrasion level. If the moisture exceeds this limit, it will have a lubricating effect and reduce the magnitude of abrasion (Kennedy and Hashemi, 1998). With the development of surface engineering, it is necessary to assess the mechanical properties of the surface in raw materials and materials covering other surfaces. In many studies, researchers have studied the effects of abrasion and corrosion on raw and uncoated materials (i.e., the surface layer and the underlying layer, respectively). Parameters affecting the wear of tillage equipment are divided into three categories; factors related to soil conditions, instrument parameters, and operational parameters (Moree and Mclees, 1980). The material of the tillage tool is one of the most important factors in determining the amount of wear. Since the operating conditions (e.g., soil texture, moisture, and time of agricultural operations) to a certain extent are controlled by the farmer, the change in the design parameters of the tilling tool has great importance in determining tool abrasion. Regarding the importance of the tillage material on the quality of tillage, friction, and wear, many researchers have modified the blade material or coated it with different materials to achieve optimal physical properties such that to reduce the wear level.

In a study, the excavation performance of a blade was assessed with eight different metal alloys. Results showed that TiN coating on of moldboard significantly reduced the wear of blades and increased their lifespan. Also, using Teflon coatings with a thickness of 0.5 to 0.8 cm on moldboard plow provided a suitable resistance to plow 20 hectares. Moreover, coating the blade with high-density polyethylene with a thickness of 0.5 to 0.8 cm on the same plow resulted in a resistance suitable for plowing 8 hectares (Nalbant and Palali, 2011). In another study, the effect of three coating methods including linear plating, pulp electrode, and electro-plasma methods with nickel coatings on plain carbon steel parts was investigated. In a linear plating method, the parts were placed in a solution containing nickel compounds as a cathode and placed in a direct current stream of nickel anode. In general, plating was similar to linear plating method, but in this method, the flow was controlled in the form of square waves. In the electroplasma method, the flow between the cathode and the anode was developed in the form of discharge of the electric charge. Then, to evaluate the wear resistance of the coatings, the weight loss percentage due to wear was measured through the field operations. The coating of linear plating increased wear resistance by 30.41%. Coatings applied to the parts by pulse plating method were able to improve wear resistance by up to 55.83% relative to raw materials. In the electroplasma technique, wear resistance increased by up to 90% relative to the base material (Abed et al., 2014). The following results were obtained by increasing the abrasion resistance of steel by creating nanocomposite cobalt-carbide tungsten (Co/Wc) on steel (steel used in tillage blades) using the electrochemical deposition method with the pulsed flow of sulfate bath. The sample weight decline was measured in a sample without coating was 0.0016 g while this value was 0.0004 g in the nanocomposite coated sample (Yazdani Motlag et al., 2012). Barzegar (2016) made an effort to improve the efficiency of the tillage operation using surface coatings. Due to the ability to crumble and reduced frictional properties of low-density polyethylene and nanocomposites, a flat blade was coated with polyethylene and nanocomposites and their wear was compared with steel by conducting tests. Experiments were performed in a heavy clay soil inside soilbox. According to the tests results, the wear rates of steel, super-heavy polyethylene, and nanocomposites were 0.22, 0.25, and 0.28 mm/ha, respectively.

Accordingly, the objective of this study is to compare the wear of parts coated with titanium nano-nitride and tantalum nano-carbide in comparison with conventional steel, galvanized steel, and fiberglass.

2. METHOD AND MATERIALS

The soil reservoir was designed and tested in order to investigate the soil and metal abrasion phenomena. To build the device, its schematic was first simulated in the SOLIDWORKS 2015 software (Fig. 1) and then it was fabricated. The soil reservoir consists of two circular skeletons of a metallic shape with an external diameter of 3 m, an inner diameter of 2 m, and a height of 50 cm. The required soil was placed in the empty space between the two plates between which the tillage tool was moving. Another important component of this device is a horizontal arm connected to the power source for dragging slider pieces on the soil. A wheel was fitted to the end of the arm to keep the balance of the horizontal arm. Considering the size, the length of the swinging arm of the slider was 1.25 m and the distance traveled at each turn was 8.57 m. Required power was supplied by a three-phase alternate current electric motor mounted at the center of the device. To obtain the progressive velocities of the horizontal arm connected to the slider unit, an inverter of VFD model 1.5 kw/220 V was used. To control the desired speeds, the inverter is positioned at a specific frequency and its value was recorded, the time of the tank movement was measured over the specified distance. By dividing the distance traveled over time, the advance speed was computed. By repeating the experiment and changing the value of frequency, the speed of 0.3 m/s was obtained at 21 Hz. A leveling device was used to smooth the soil surface due to the movement of the plate on the surface of the soil

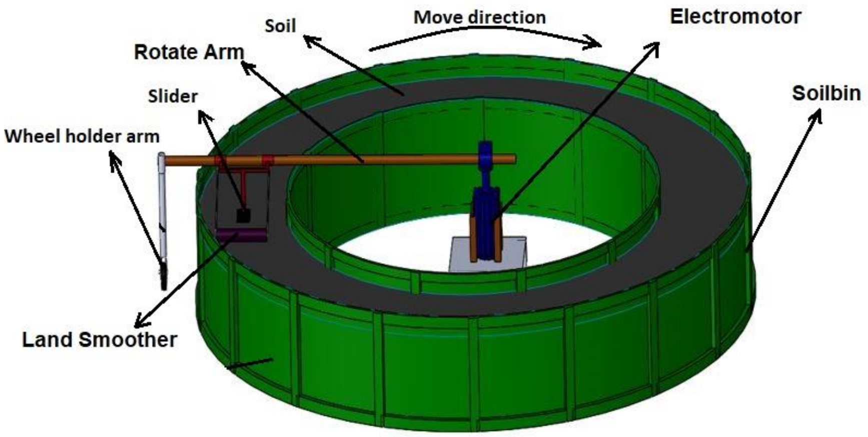

Figure 1: Soilbin designed using Solid works 2015 software

Experiments were performed using 5 types of slider parts of normal steel (st37), galvanized steel, fiberglass, titanium nano-nitride coated (TiN), and Tantalum Nano Carbide (TaC) with the dimensions of 10 × 10 cm. The front part of the plates was slightly curved upward to allow smooth and fluid motion (Fig. 2).

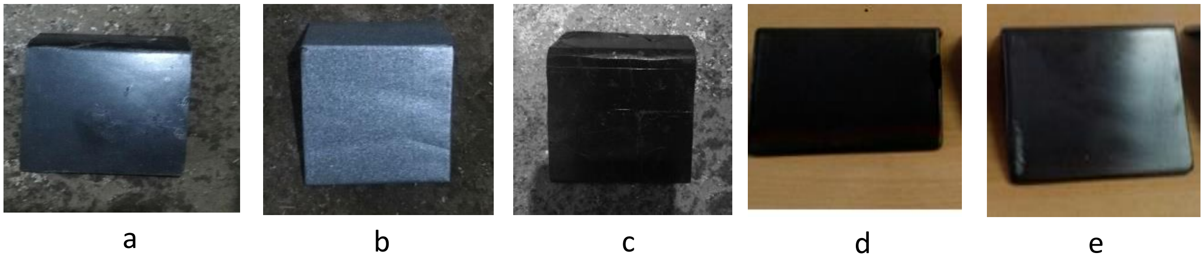

Figure 1: Different material types were used, a) steel, b) galvanized steel, c) fiberglass, d) Tantalum carbide, e) Titanium nitrite parts

The nanoscale nano-layer surface layer was applied by a sputtering method in a plasma-ionized medium in a vacuum chamber at a pressure of about 10 mbar with a thickness of about 100 nanometers based on simple carbon steel. Fig. 3 presents the AFM images of titanium nano-nitride and tantalum carbide specimens showing the surface morphology of the samples after the mapping layer. A pale yellow to reddish color spectrum represents the particles topography on the surface. Wherever the yellow points are found on the sample surface, the particle size was larger and the surface of the sample was more rugged. In comparison, at reddish areas, the particles were smaller in size and the surface level was uniform. Therefore, with increasing surface roughness, the coating will be detached and its corrosion and abrasion resistance will be less. The smoother the surface, the more resistant it would be against the wear. Hence, smaller nano-coating particles will help to improve the coating's properties such a wear resistance. Regarding the surface topography of the samples, it was concluded that the particles are in an approximate small range, confirming the proper and smoother surface and uniformity with a thickness of 100 nm (Gupta et al., 2007).

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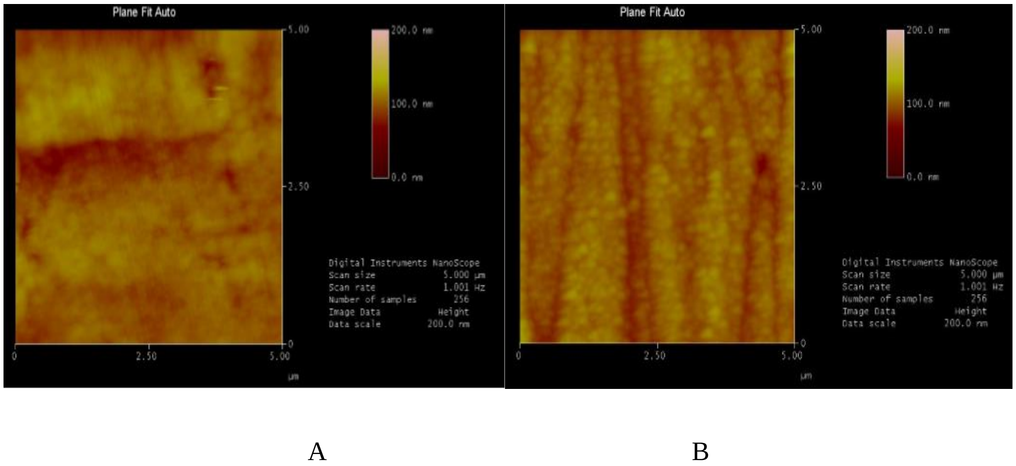

Figure 3: Topography A sample of titanium nitride nano - B: Nano Tantalum carbide

Since the texture and size of the soil aggregate are directly related to the wear of the tillage tool. For this, plates were tested in three textures of Sandy loam, Loam and Clay loam with 10% moisture content, their characteristics presented in Table 1.

Table: Soil texture Tested

Soil texture	Sand percentage	Clay percent	The label is a percentage
Sandy loam	73	10	17

Loam	46	24	30
Clay loam	30	40	30

Each slider part was moved over three distances of 500 m and a total distance of 1500 m with a constant velocity of 1.8 km/h. Also, a vertical load of 20 N was applied on the surface of the plate to induce tool wear. To evaluate the created wear, the weight loss method was used (Natsis et al., 2008). To measure the weight of the plate, a digital scale EK4000 model (Made in Japan) with a precision of 0.001 gr was utilized.

In all weighing steps, the plate was washed and cleaned of other materials. As a result, the weight difference of the blade with its previous value was equal to the plate wear in the operation time. The wear percentage of the blades was determined by Eq. (1):

$$100 \times \frac{W1 - W2}{W1} = P\% \qquad (1)$$

W_1 = the initial weight of the plate, gr

W_2 = secondary weight of the plate, gr

3. RESULTS AND DISCUSSION

All data on weight loss due to plate wear were obtained in percentage. Data were analyzed in a completely randomized factorial design using Minitab2013 software. According to the obtained results (Table 2), there was a significant difference in the effect of soil texture, plate material, distance, their binary effect, and a triple effect interaction at 1% probability level.

Table 2 Results of analysis of variance of the effects of the tested agents on wear

Source	DF	SS	MS	F
Soil texture	2	2 0.4845	1.24227	9436.99**
Traveled distance	2	2 0.4786	1.23931	9414.51**
Plate material	4	16.1530	4.03824	30676.88**
Soil texture * Traveled distance	4	0.1831	0.04577	347.71**
Soil texture * Plate material	8	1.3314	0.16643	1264.29**
Distance * Material	8	1.5283	0.19104	1451.22**
Soil texture* Traveled distance * Plate material	16	0.1931	0.01207	91.67**
Error	88	0.0116	0.00013	
Total	134	24.3637		

**highly significant

Fig. 4 shows the effects of the plate material and traveled distance on abrasion of the plate in three soil textures. The wear percentage of the plates is shown in the three travel stages. The gradient of the graph in the first stage of travel (the first 500 m) was more in comparison to other traveled stages, suggesting a high wear percentage. The wear value was higher in sandy loam soil than loam and clay loam. This difference is due to the fact that the diameter of sandy loam soil aggregates was coarser than that of two other soils (Mckeys, 1985). In the second stage, due to the removal of the fragile layer, the gradient of the graph was reduced. Finally, in the third stage, all samples showed almost similar behaviors against wear. Therefore, by reaching the third stage of travel, a lower contact area between soil and plate existed. Therefore, it can be stated that the reduction of abrasion can be due to the gradual increase in surface hardness (Yilmaz et al, 2006). Among the 5 plates examined, SST37 showed the highest wear

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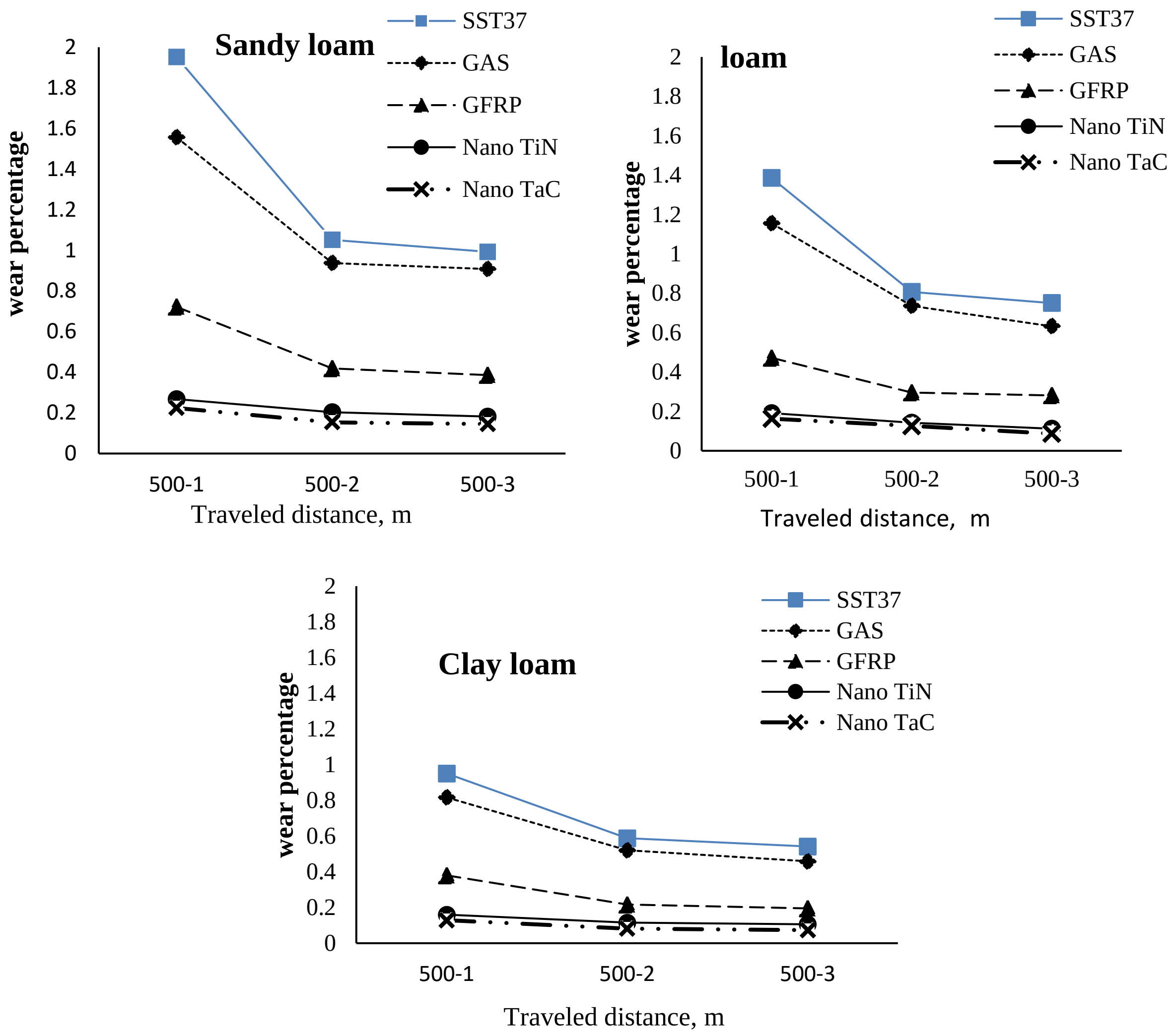

Figure 4: wear pattern in work stages in three soil texture

Fig. 5 compares the average wear in a total distance of 1500 m in three tested soils for five tested plates. The highest wear percentage of 4% occurred for SST37 plate in sandy loam soil, which was the highest value of wear in all stages. Galvanized steel with a total abrasion percentage of 3.31% was in the next rank. The important point in this regard is the high resistance of the glass fiber to the abrasion. Fiberglass with total wear of 1.52% showed a significantly high wear resistance than the SST37 steel and galvanized steel. Its resistance to wear was more than 2.5 times of SST37 steel on average. Fiberglass with a reinforced fiber structure with polymer materials increases the hardness and stiffness of the sample and ultimately improves the resistance of the unit to abrasion (Wang et al., 2002). Nanocoated plates (i.e., TaC and TiN paltes) exhibited the best performance with 0.52 and 0.65% wear, respectively. Compared to conventional steel with a weight loss criterion, it improved about 7 times the wear resistance, which makes it the most optimal materials in this study (Nalbant et al., 2011). .

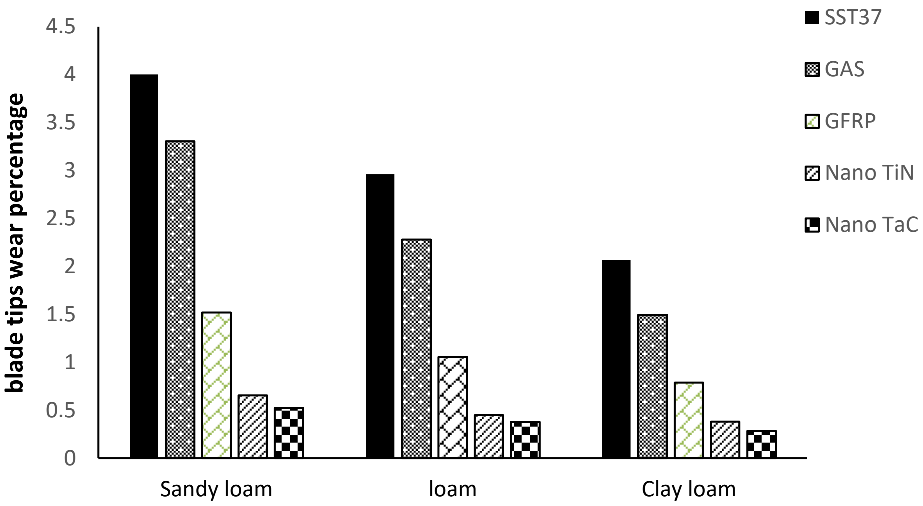

Figure 5: Comparing the percentage of wear of plates in total three stages of travel (1500 m) in three types of soil

Loam soil has the highest degree of wear after sandy loam. However, the lowest abrasive data was for clay loam texture. It contained fine aggregates that led to the lowest abrasion. The maximum value of wear in total distance of 1500 m was 2.07, 1.49, and 0.79% for SST37 steel, galvanized steel, and fiberglass, respectively. The lowest wear values of 0.29 and 38% were obtained using TaC and TiN nanocoatings, respectively. It can be concluded that nanoscale coatings, because of the smooth surfaces on the scale of nanoscale, reduced the contact area with hard particles in the soil. In the first stage, travel maintains wear resistance at a high level. Ultimate wear was very low for nano-coated plates. Additionally, the use of a plasma-coating process exhibits more abrasion resistance and component strength than conventional coatings. The electroplasma deposition creates an extraordinary adhesion between the surface of the base and the coating particles. It has to be noted that the size of the nanoparticles has major changes in wear and corrosion resistance. As the size of the particles decreases, the number of atoms in the boundaries or coating surfaces increases sharply. There is a direct relationship with the surface coated surface roughness and a decrease in wear resistance, corrosion, and high friction coefficient.

1. CONCLUSION

It was found that the percentage of plate wear was higher in the first stage of travel (500 m) than the second and third stages. High wear was due to the physical structure of plates. After the operation, for a while, the physical structure of the plate surface showed a regular shape. Therefore, by reaching a certain level, a lower area of the plate was in contact with the soil. Also, it was found that the reduction of abrasion can be due to the gradual increase in surface hardness.

Comparing the amount of abrasion between the plates used revealed that SST37 steel and galvanized steel had the highest weight loss, in the order of their appearance. Fiberglass compared to these steels had showed less abrasion. The important point of this study is the use of Titanium nano nitrite (TaN) and Tantalum nano carbide (TaC) coatings. Abrasion resistance of the nanocoated plate was 7 times that of the uncoated steel. This difference can be attributed to the fact that TiN and TaC nanoparticles applied with an electroplasma method have good adhesion and increase the abrasion resistance because of the formation of a smoother surface and free of cracks. Comparison of the mechanism of the abrasion percentage between two TaC nanocoatings with less abrasion percentage than TiN revealed the lowest weight loss in the abrasion test. Moreover, the TaC nanocoating was found as the most optimum material for using in tillage.

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