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Determination of the Wear Resistance of 5630 Steel Cultivator Tine Coated with Titanium and Nickel

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Abstract**—***Soil tillage tools change their shape by wearing down due to various reasons both in the field and out of the field. As a result, the energy requirement increases, the worn part cannot perform its functions, and the operating success decreases. Time losses also show permanent risks in relation to production. Another negativity is that the worn steel parts are released into soil. As a solution to these problems, it does not affect the use of Titanyum and Nickel plating in this thesis. For this purpose, the shares of the cultivator with 5630 Steel loads were coated with Titanium and Nickel and tested in different terrain areas. The etching process was carried out using the etching test setup under the conditions of the end iron laboratories covered with the electrochemical deposition system. Then microstructure coating was done. Hardness, amount of aging, wear values were determined and coated and uncoated end irons were compared. In tests, when the hardness of 5630 Steel reaches 79.7 (HRB) before coating, it turns out to be 81.6 HRB when Nickel plated and 82.7 HRB when Titanium is plated. In the abrasion growth test, the maximum was 1.33-2.02-3.05 before coating, respectively, under 5-10-15 N load. 1.19-1.73-2.9% when nickel plated, 1.17%-1.68-2.55% when Titanium coated.*

Keywords**—** *Steel, Cultivator, Tine, Wear, Coated, Titanium, Nickel*.

I. INTRODUCTION

This The alteration occurring on surfaces caused by the dissociation of small particles due to mechanical stress (in some cases, chemical factors) is called wear (1). This definition illustrates that corrosion is within the domain of wear. However, it also suggests that the emphasis is on the deterioration of material surfaces due to mechanical forces (2). Wear is the slow elimination of particles from a surface because of a mechanical action. This definition excludes corrosion and peeling. Because corrosion does not comply with the standard of "mechanical effect" and peeling does not comply with the "slow" condition of wear, they are not taken into consideration while discussing wear (2;3).

The dissociation of small particles due to mechanical forcing on surfaces (in some cases by chemical factors) for various reasons, and the changes caused as a result are defined as wear. In the initial definition, corrosion is qualified as a type of wear. The definition pays particular attention to various types of wear on the material surfaces caused by mechanical parameters. Wear is the slow removal of particles from the surface by mechanical action. The specified definition disqualifies corrosion and peeling as wear. Since corrosion does not comply with mechanical effect and since peeling does not comply with slowness, they are not regarded as in the realm of wear.

Electrochemically deposited coatings, in accordance with laboratory observations and tests pertaining to the kinetic impact of corrosion, are utilized as a strategy to forecast corrosion behaviour and enhance the wear resistance of cultivator shares. Furthermore, the technique's applicability is enhanced by its close proximity to coating and its alignment with corrosion analysis using electrochemical methods.

As soil cultivator tools deteriorate and lose their shape for various causes, the amount of energy required for the operation increases. Additionally, replacing worn parts leads to increased time and production expenses. The inclusion of steel in the soil, the need for frequent replacement of wearing parts, and the resulting productivity and labor losses have significant detrimental effects on the agricultural economy.

The objective of this research is to enhance the durability of cultivator shares by employing a new technology called Electrochemical Deposition and Coating Method, which involves coating the steel shares of cultivators with titanium and nickel. This will result in a reduction of metal release into the soil caused by wear, leading to decreased wear and lower agricultural production costs associated with part replacement and repair. Additionally, this approach will save time and contribute to overall economic benefits.

II. MATERIALS AND METHODS

1. Materials

The study involved calculating the wear values of 5630 steel cultivator tines that had been previously utilized in agricultural settings. Furthermore, a chemical thermal deposition process was employed to coat 5930 steel with titanium and nickel. Subsequently, this coated material underwent testing on an abrasive wear test device. The wear levels of the cultivator shares were assessed in the agricultural areas of the Faculty of Agriculture in Muratlı District. Subsequently, experimental wear tests were conducted using a wear test equipment at the laboratory of the Mechanical Engineering Department at Çorlu Engineering Faculty.

The application of a protective layer onto the cultivator shares (coating) was carried out within the Physics Department's laboratory at the Faculty of Arts and Sciences. The experimental research utilized the Gamry Reference

3000-Potentiostat/Galvanostat device. The coating processes were controlled and characterized using the "PHE200 - Physical electrochemistry techniques software". A computer was present controlling the electrochemical cell and potentiostat device and the results were processed and recorded in it.

BSM 150-C model and HARTIP 3000+ devices produced by Bulut-Makine Sanayi ve Ticaret Limited Şirketi were used to measure the hardness of the cultivator shares.

1.1. Wear Test Setup

The abrasive wear test setup used to determine the wear resistance of Titanium and Nickel coated 5630 steel material is given in Figure 1.

Front

Side

Fig. 1. The wear test setup

This device has been specifically engineered in accordance with the ASTM G174-04 standard for the purpose of conducting wear testing. The gadget utilized 80 mesh SiC sandpaper as the abrasive material. The specimens were subjected to abrasion using identical time and distance parameters, with applied loads of 5, 10, and 15 N. Subsequently, the weight losses were measured and recorded (Can, 2020; Kaya, 2022).

1.2. Preparation of Samples for Microstructure Examinations

To facilitate optical inspections of the samples, they were prepared by cutting them with guillotine scissors into dimensions of 20x30x5 mm. The produced samples underwent SEM - EDS analysis, and microstructure pictures were captured using the Quanta FEG 250 brand device (Figure 2).

Fig. 2. Quanta FEG 250 Brand SEM Device

1.3. Cultivator Shares Used in the Research

The cultivator share used in the research was a narrow two-ended cultivator share, which is widely used by manufacturers. The chemical analysis result of the cultivator share material used is given in Table 1.

TABLE I. Chemical properties of the spring cultivator share used in the experiment

C	Si	S	Mn	P	B	Ti
0,27	0,40	0,02	1,15	0,025	0,0008	0,08

III. METHODS

The hardness values of the coated 5630 steel material were determined in the laboratory and wear tests were carried out in the wear test device, and then the coating was applied. Subsequently, wear resistance was demonstrated by repeated wear.

1. Coating Samples through Electrochemical Deposition Method

Ti and Ni thin films were enlarged using a two-electrode low-cost electrochemical growth system using titanium (IV) isopropoxide (Ti[OCH(CH3)(2)](4)) and Nickel(II) sulfate hexahydrate (NiSO4 6H2O) chemicals. Since the reference electrode may cause pollution, the three-electrode system was converted into a two-electrode system as shown in Figure 3. In the two-electrode system, 5630 steel material was used as the cathode and high purity graphene was used as the anode.

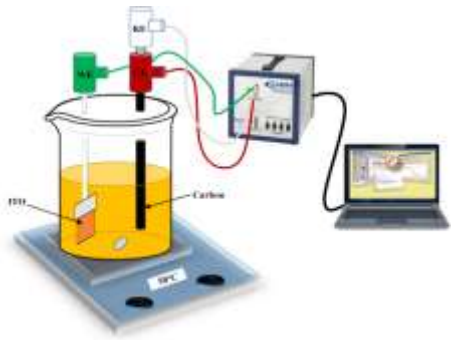

Fig. 3. Electrochemical deposition system with two electrodes

Ti and Ni thin films were pulsed deposited using an electrochemical deposition system. In the pulsed method, Ni: 0.45V-0.5s and 0V-4.5s and Ti: 0.45V-0.5s and 0V-1.5s were applied. By employing this technique, thin films exhibit enhanced adhesion to the substrate and result in a smoother surface.

2. Cyclic Voltammetry

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The analysis of the electrochemical properties of chemicals in solution is done using the cyclic voltammetry technique. The cyclic voltammetry technique is the technique in which the current resulting from the change in potential within a certain range is measured. The voltage of the working electrode is measured by looking at a fixed reference electrode. In Figure 4 below, the electrical signal of the applied voltage is shown by looking at the reference electrode. According to the figure, the potential scanned negatively from point a to point d with a lower value. Point d here is the transformation potential. Point d, which is the peak in the reduction or oxidation of an ion, is a suitable voltage value. It scanned in the opposite direction, from point d to point g, in a positive direction. In this case, there was reduction from point a to point d, and oxidation occurred from point d to point g.

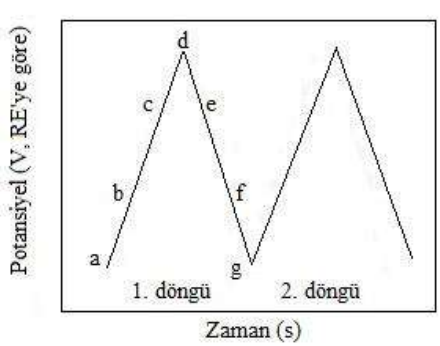


Fig. 4. Potential signal in accordance with cyclic voltammetry reference point

Here the scanning speed can be adjusted and the cycle can be continuous. Scan rate can be calculated using the slope of the stimulation signal. The cyclic voltammetry is obtained by measuring the current of the working electrode throughout the entire scan.

The cyclic voltammetry formed by reducing and oxidizing the electrode is shown in Figure 5. Reduction occurs by scanning the field in the negative direction and the resulting current is cathodic current. Epc is reached when all the ions on the electrode surface are reduced. This point is the equipotential peak. After the potential reaches point d, positive scanning occurs in the scanning from point d to point g. In this case, oxidation occurs and anodic current occurs. When all the ions on the electrode surface are oxidized, the anodic peak potential, Epa, is reached. The relationship between Epa and Epc is expressed as follows (6).

Epa-Epc=0,059/n (1.1)

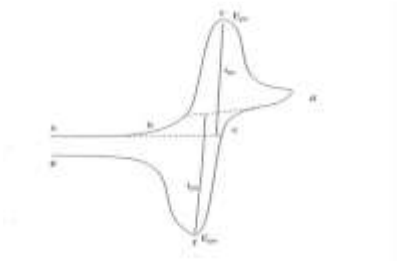


Fig. 5. Cyclic voltammetry voltage variation

Anodic and cathodic peak currents can be calculated using the Nernst equation:

İp=(2,69x⟦10⟧^15) n^(1/2).A.D^(1/2).C.v^(1/2) (1.2)

When we examine the equation, the terms stand as follows: Ip: peak current in amperes, n: amount of electrons, A: electrode area in cm2, D: diffusion coefficient in cm2/h, C: molar concentration in mol/cm3, V: scanning speed in v/h.

Cyclic voltammetry studies applied within the scope of this study were carried out with a scanning speed of 20 Mv/h, and the results were recorded by first scanning in the cathodic direction and then in the anodic direction.

3. Determination of Hardness Value

Measurements were carried out to the TS 140 and 139 standards. The hardness of 5630 steel material and the cultivator shares made from this material was measured using a BMS 150-C type hardness measuring device from Bulut Makina. In the Rockwell B (HRB) hardness test, the hardness was measured by applying a preload of 10 kg, a total load of 100 kg, and using a ball tip.

In the hardness measurement of the coated samples, the HRB hardness of the samples was measured by using the prototype HARTIP 3000+ series device hardness measuring device of Bulut Makina.

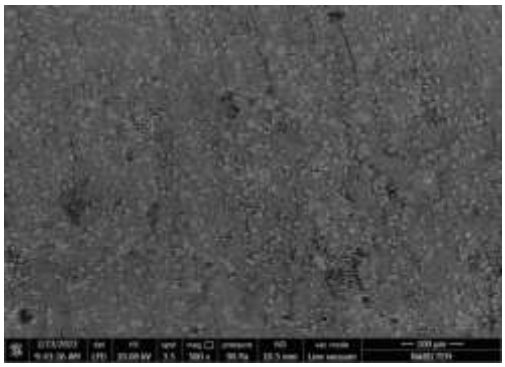
4. Determination of Abrasive Wear Value

Coated and uncoated samples were carried out for abrasion testing on a device designed according to the ASTM G174-04 standard. 80 mesh SiC sandpaper was used as abrasive in the device. A new section of sandpaper was used for each sample. Experiments were carried out for 400 m wear distances under 5 N, 10 N and 15 N loads. In order to make the tests shorter, the speed was kept high and the time-dependent distance calculated from the engine speed was calculated as 400 m in 30 seconds.

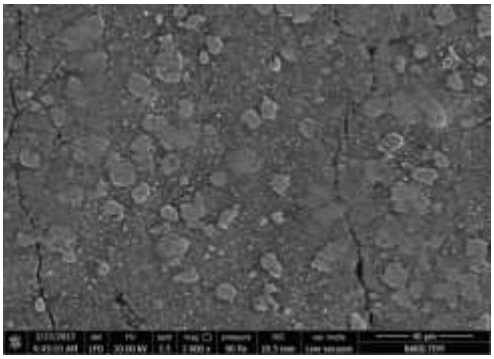
IV. RESULT AND DISCUSSION

1. Microstructure Images

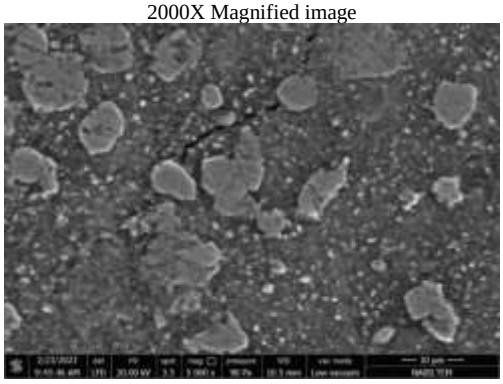
The images obtained with an electron microscope were obtained without gold plating. The analyzes were carried out at three different magnifications (500X, 2000X, 5000X) with a spot beam diameter of 3.5 at 20 kV accelerating potential. The electron microscope views of the 5630 Steel material used in the research are given in Figure 6.



500X Magnified image



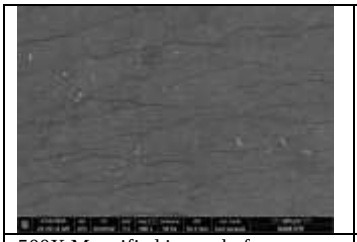
2000X Magnified image



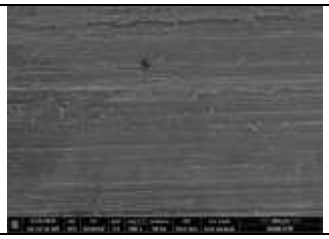
5000X Magnified image

Fig. 6. Electron microscope images of 5630 steel material

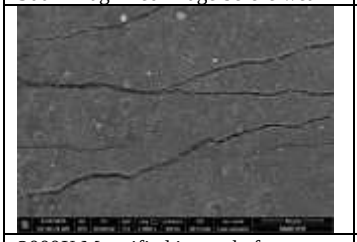
SEM surface images of 5630 steel material which is coated with nickel and titanium were obtained on the electron microscope before and after wear, and the nickel coated steel material is shown in Figure 7 and the titanium coated steel material is shown in Figure 8.



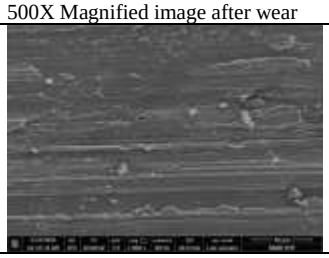
500X Magnified image before wear



500X Magnified image after wear



2000X Magnified image before wear



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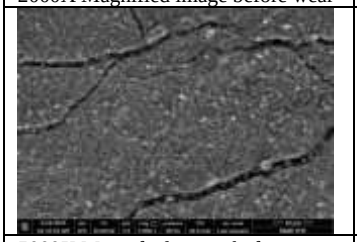
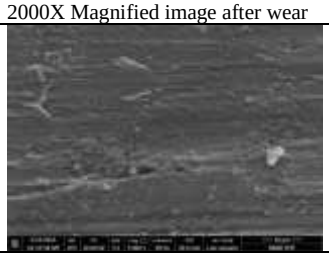


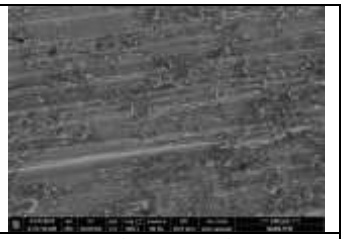
5000X Magnified image before wear



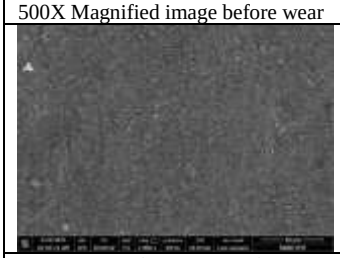
5000X Magnified image after wear

Fig. 7. Electron microscope images of nickel-coated 5630 steel material

500X Magnified image before wear



500X Magnified image after wear



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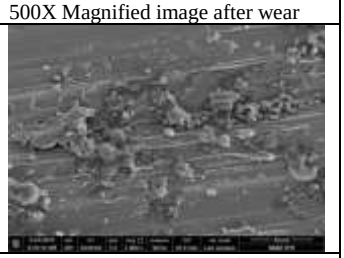
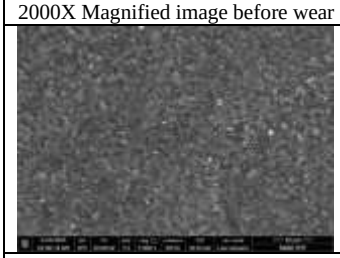
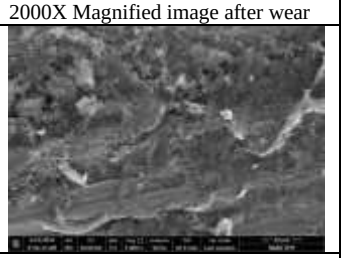


2000X Magnified image after wear



5000X Magnified image before wear



5000X Magnified image after wear

Fig. 8. Electron microscope images of titanium-coated 5630 steel material

The surfaces of the steel were rough compared to the raw samples, but a smooth surface was obtained after coating the surfaces of the raw steel. According to this result, it can be seen from the figures that the coating process of the surfaces was carried out successfully and homogeneously. Similar results were obtained in other studies (4;5).

2. Hardness Value Results of the Samples

The hardness values of the 5630 steel used in the research and the samples of the steel material coated with nickel and titanium are shown in Table 2. It has been observed that the hardness of the steel material increases with surface coating (Figure 9). Similar results were obtained in other studies (7;8; 9;10).

TABLE 2. Hardness values of the samples used in the research.

Material	Replication	Hardness Value (HRB)
5630 steel material	1	79,2
	2	80,3
	3	78,4
	4	80,7
	Avarage	**79,7**
5630 steel NICKEL coated material	1	83,2
	2	82,1
	3	80,2
	4	81,0
	Avarage	**81,6**
5630 steel TITANIUM coated material	1	83,1
	2	82,4
	3	82,9
	4	82,5
	Avarage	**82,7**

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During hardness measurements, it was noted that the 5630 Steel material exhibited HRB values ranging from 78.4 to 80.7. The hardness values exhibited a rise subsequent to the application of the coating, reaching a range of 80.2-83.2 HRB upon completion of the nickel coating process. The titanium coating led to a measurement range of 82.4-83.1. The mean hardness value of 5630 steel was determined to be 79.7 HRB, whereas the highest hardness value of 82.7 HRB was achieved with the application of a Titanium coating (Figure 9).

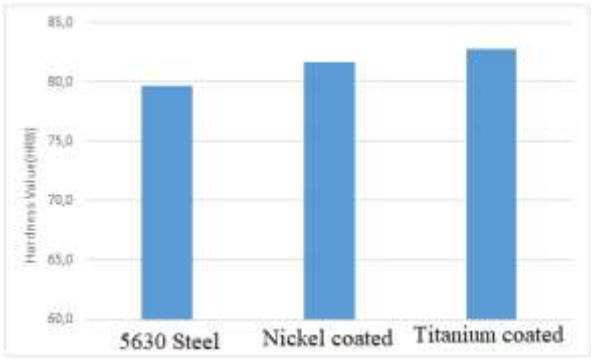

Fig. 9. Hardness values of the cultivator shares used in the research

3. Abrasive Wear Results

Based on the experiments conducted in the abrasive wear test setting, it was found that the surface coating enhanced the wear resistance. The experimental findings are presented in Table 3.

The weight loss of 5630 steel material varied between 1.30% and 1.33% when a force of 5 N was applied. When the applied force is increased, these values range between 1.96% and 2.02%, while under the influence of a 15 N force, they vary between 3.01% and 3.09%.

The weight loss of 5630 Steel material, when coated with Titanium, is contingent upon the magnitude of the applied forces during wear. The weight loss exhibited a variation of 1.11-1.19% when a force of 5 N was applied. Upon increasing the applied force, the data exhibited a range of 1.61-1.73%. However, when a force of 15 N was applied, the values showed a variation between 2.86-2.90%.

When 5630 Steel material is coated with Titanium, the weight loss after wear varies depending on the forces applied. When 5 N force was applied, the weight loss varied between 1.11-1.19%. When the applied force was increased, these values were 1.61-1.73%, but with 15 N force, they varied between 2.86-2.90%.

Based on these findings, it was noted that the application of a coating resulted in a decrease in weight loss after wearing. Although the ratio remained relatively constant when a 5 N force was applied, it progressively increased when the force was raised. The highest ratio was observed when a force of 15 N, the maximum force employed in the studies, was applied.

In the analysis performed to determine the difference between the group averages for the Average Weight Loss Percentage After Wear (%) in terms of the applied forces (5, 10 and 15 N) in 5630 steel material, it was determined that the difference between the groups was significant ($p < 0.01$). According to the Duncan multiple comparison test, which was performed to determine which group average caused the difference between the averages, it was observed that there was a difference between the averages in all groups ($p < 0.05$).

TABLE 3

Material	Applied Force (N)	Initial Weight (g)	Final Weight (g)	Wear Amount (g)	Percentage of Weight Loss after Wear (%)	Avarage of the Percentage of Weight Loss after Wear (%)
5630 steel material	5	28,109	27,739	0,370	1,32	1,32±0,01a
		28,108	27,742	0,366	1,30	
		28,106	27,733	0,373	1,33	
	10	27,739	27,187	0,552	1,99	1,99±0,02b
		27,639	27,08	0,559	2,02	
		27,756	27,213	0,543	1,96	
	15	27,301	26,458	0,843	3,09	3,05±0,02c
		27,202	26,384	0,818	3,01	
		27,187	26,359	0,828	3,05	
5630 steel NICKEL coated material	5	27,770	27,451	0,319	1,15	1,15±0,02a
		27,772	27,464	0,308	1,11	
		27,768	27,437	0,331	1,19	
	10	27,451	26,992	0,459	1,67	1,67±0,04b
		27,453	26,978	0,475	1,73	
		27,449	27,008	0,441	1,61	
	15	26,992	26,214	0,778	2,88	2,88±0,01c
		26,994	26,211	0,783	2,90	
		26,990	26,219	0,771	2,86	
5630 steel TITANIUM coated material	5	27,796	27,480	0,316	1,14	1,14±0,02a
		27,798	27,489	0,309	1,11	
		27,794	27,469	0,325	1,17	
	10	27,480	27,030	0,450	1,64	1,64±0,02b
		27,482	27,021	0,461	1,68	
		27,478	27,037	0,441	1,60	
	15	27,030	26,355	0,675	2,50	2,50±0,03c
		27,032	26,344	0,688	2,55	
		27,028	26,366	0,662	2,45	

As can be seen in Table 3, with a force of 5 N, the wear loss in 5630 steel material is 1.32%, in the nickel coated material it is 1.15% and in the titanium coated material it is 1.14. Similar values were also obtained for other forces. In the coating, the wear loss in the material coated with titanium was

determined to be less than in other materials. The relationship between material coating property and wear loss is shown in Figure. As can be seen in the Figure, the amount of wear under force decreased for the samples whose hardness increased by coating them. There is an inverse proportion between the hardness value and the amount of wear. Similar results were obtained in previous studies (Mutaf and Ulusoy, 1977; Kantarcı, 1982; Raval and Kaushal, 1990; Bayhan, 1996).

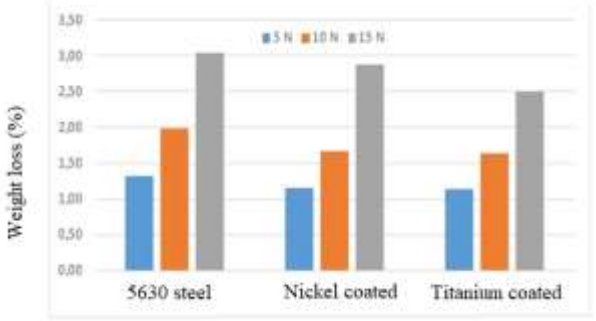

Fig. 10. Percentage losses of steel materials and nickel and titanium coated steel materials

IV Conclusion

The wear value of this study, conducted on the abrasive test device in the laboratory, with a force of 5 N, the wear amount on 5630 steel material is 0.370 g, the loss is 1.32%; the wear amount is 0.319 g, and the loss is 1.15% in the nickel-coated material; and the wear amount is 0.316 g, and the loss is 1.14% in titanium-coated material. Similar values were also obtained for other forces. The wear loss is the least in the titanium-coated material when compared to the others.

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