Chisel plough shares protection by using two different coating techniques

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Abstract: Hydrophobic coating with ceramic, as nanotechnology, is widely used to protect metal in different industries, but it has not yet tested with agricultural tools. Nickel chrome plating is defined and used process to protect metals too, but it has a common use. So, this work discusses the effect of two types of coating techniques on wear reduction on normal chisel plough shares. First coating technique was using nanotechnology inform of SI14-200 micron (0.2 mm) high density hydrophobic and ceramic coating. Second coating technique was using the galvanizing process by treating the shares with nickel chrome plating. Both techniques were applied for chisels' shares made from medium carbon DIN C-45 steel (AISI 1045/ JIS S45C). All treated shares were operated for 40, 80 and 120 hours to observe wear characteristics and it was compared to the control untreated shares. Weight loss of chisel plough shares and dimensional wear loss percentages were recorded as dependent parameters. Shares treated with hydrophobic and ceramic coating gave promising results during first 40 working hours with average weight loss values of 0.49% because of the lower abrasive action and friction of coated materials. While, weight loss values obtained by using chisel plough shares without treatment were the highest at all working hours. Control chisel shares gave the highest differences in dimensions in mm. The lowest differences in dimensions obtained when using shares treated with hydrophobic and ceramic coating, where, average differences between original and final dimensions at six different points along with shares width and length were 1, 1, 2, 2, 2, 1 mm after using the shares for 40 working hours. At higher working hours, 80 and 120 h, the better values either for weight loss or for differences in dimensions achieved by shares treated with nickel chrome plating. Cost of treating shares with nickel chrome plating is higher than using hydrophobic and ceramic coating but it gives long working life, lower required drawbar pull forces and better performance for chisel shares.

Keywords: Nanotechnology, hydrophobic coating, nickel chrome plating, wear characteristics, farm machinery

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1 Introduction

Soil tillage is defined as a modification of soil structure due to the mechanical work of tillage tools and it is a fundamental phase of agricultural production. This work involves large amounts of energy necessary to break down, invert soil layers, reduce clod size and rearrange aggregates, and cause significant wear to tillage tools (Formato et al., 2005; Hernanz and Ortiz-Canavate, 1999). Shares, as parts of ploughs, are exposed to wear during service. Those parts are worn because of the abrasive action of the soil particles, which depends on the soil moisture and composition (Bayhan, 2006; Zhang and Xing, 2014).

The wear of soil tillage tools by abrasion of soil particles highly corresponds to mechanical and microstructural properties of material which are tools made of, on the soil texture and also on the working conditions such as the cultivation depth and the soil

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water content (Owsiak, 1997). Plough shares are less worn if used on moist clay and loam soils and if used on moist sandy soil, then the wear of plough shares is greater (Natsis et al., 1999). During service, the first to become blunt is a plough share tip and then the blade (Banaj et al., 2008; Filipović et al., 2003). Also, the intensity of the plough share wear is increased along with the increase of sand content in the soil (Opačak et al., 2017; Miloš et al., 1993; Bobobee et al., 2007). Rana (2017) concluded that material composition of blades affects wear characteristics of two types of blades, Austempered Ductile Iron (ADI) rotavator blades compared to indigenous and imported rotavator blades. The test result showed that average gravimetric wear rate of ADI and indigenous blades were 110.08%, 129.98%, 154.42% and 106.87% of imported blade. Because of the wear and bluntness, plough shares need to be replaced with new ones, thus causing delays in service, increasing costs and lowering the efficiency of a tractor.

The wear protection methods have essential assumption that higher material hardness increase abrasion wear resistance, but influence of the material characteristics on wear is very complex and often depends on additional impacts. To achieving optimal solution of abrasion wear protection methods have to combine tribosystem analysis as well as a laboratory and exploitation investigations (Ivusic and Jakovljevic, 1992). Several methods have been developed over the years to increase the abrasive wear resistance of tillage tools. Hard facing is a commonly employed method to improve surface properties of tillage tools where an alloy is homogeneously deposited onto the surface of a basic material by different techniques of welding, with the purpose of increasing hardness and wear resistance (Buchely et al., 2005; Mihaljevic, 1993).

A wide variety of hard facing alloys is commercially available for protection against wear, so the proper material selection becomes difficult. Selection of the material should be considered on the basis of finished hardness, microstructure, mechanical properties and wear resistance of a particular type of steel (Bhakat et al., 2004). Hydrophobic with ceramic coating or protection by nano-coating as protective shell for agricultural tools not yet tested, and there is no much studies regarding its use. So, in the current research work, hydrophobic and ceramic coating techniques was tested against other well-known nickel chrome plating to study their effect on the chisel shares wear behavior. And for farm machinery management point of view, more studies about such protection materials may help reducing farm machinery operational cost.

2 Materials and methods

Experiments were conducted at Department of Agricultural Engineering, Faculty of Agricultural, Kafrelsheikh University, Egypt in year 2019. The Experiments were done on same soil type (moist sandy loam soil) which was prepared in soil bin for higher intensity of the plough share wear (Table 1). Experiments were done with two independent parameters; coating techniques and number of working hours and two dependent parameters; shares weight loss and dimensional wear loss percentages (dimensions variation before and after operating). First coating technique was nanotechnology coating (Hydrophobic with ceramic coating), second coating technique was nickel chrome plating, and both techniques were applied for chisel shares made from medium carbon DIN C-45 steel (AISI 1045/ JIS S45C, medium carbon steel offering tensile strengths in the modest range) and was compared to normal chisel share without treatment (control). Three values of working hours were chosen; 40, 80, 120 hours to study the effect of coating on wear characteristics.

Table 1 Particle size distribution and $CaCO_3$ content

Depth, mm	Sand % 2-0.02 mm	Silt % 0.02-0.002 **mm**	Clay % < 0.002 **mm**	Texture Class	$CaCO_3$ %
0-200	61.24	23.64	15.12	sandy loam	1.4
200-400	62.18	20.54	17.28	sandy loam	1.8

2.1 Soil bin

The experimental set-up for chisel plough share wear study comprised a rectangular open air soil bin (Hegazy, 2017) as an experimental unit. Soil bin was used to test the effect of using two types of coating on wear reduction for normal chisel plough. The designed soil bin done to make it multipurpose with dimensions of 10 × 1.5 × 1.2 m as length, width and height respectively. Soil bin has free capacity of 18 m^3 and prepared to contain most available soil and media under different conditions. The soil bin was rectangular in shape and withstand under heavy conditions with multi-duty facilities. Materials used to manufacture soil bin were steel, cast iron, hollow sections iron, wood, railway type move and wheels. Additional frame have been manufactured and used to carry required shares, movable material and units, with dimension of 1.5 m× 0.7 m× 0.5 m as width, length and height respectively and to be movable above the main frame of the soil bin. High quality materials and equipment used to provide the soil bin with required movement and desired arrangements. Two different 5 hp motors and inverter have been used to provide the required continuous movements of the carriage during test in two directions, forward and backward. Soil bin' floor and walls covered by beech wood and plastic sheets to maintain the water and drainage. Electrical connections and circuits have been done carefully to control all movements and motors in on control unit attached to the soil bin (Figure 1).

Soil moisture was kept in the range of 10%-16%. Samples were oven dried for 24 h at 105°C to check moisture content frequently. Before starting the experiments soil was filled up to certain fixed level in a container with 4.5-5 kg cm^{-2} compaction force. Loss in weight indicated the moisture evaporated from that known volume of container. During chisel shares wear testing, the treated chisel shares and control were fixed together on the soil bin carriage and were in equal distances and ploughing depths. After certain times of operating chisel shares, the ploughing depths increased to make the working condition stable as possible during the working time till the soil gets prepared and re-compressed again.

Figure 1 Soil bin, attached control units and two-direction motors

2.2 Coating techniques

2.2.1 Nanotechnology

Based on the well-known unique nanotechnologies, the material used to coat the chisel plough was a hydrophobic coating spray with additional ceramic coating, which is nano-sized but thick enough to protect shares against scratches, chemicals, corrosion and wear. The advantage of nanotechnologies is to provide more durability, better repellency, and resistance in comparing with normal metal without treatment. The spray was SI14-200 micron (0.2 mm), final shape of treated shares is presented in Figure 2a.

2.2.2 Galvanizing and plating process

Nickel chrome plating is the most common plating technique that utilizes nickel and chromium electrodeposits to form a multiple-layered finish on a substrate. Many industries use this process. It forms a hard outer layer that improves the corrosion and wear resistance of the substrate. Electrodeposited metal on the surface of a substrate has been used in engineering applications to provide superior qualities in the form of a thin layer of coating. Nickel is mostly applied for the purpose of corrosion resistance, while chromium does the decorative part of the plating process. In case of chisel shares, the thickness of the layers was adjusted for aesthetic value and more hardness final shape of treated shares is presented in Figure 2b.

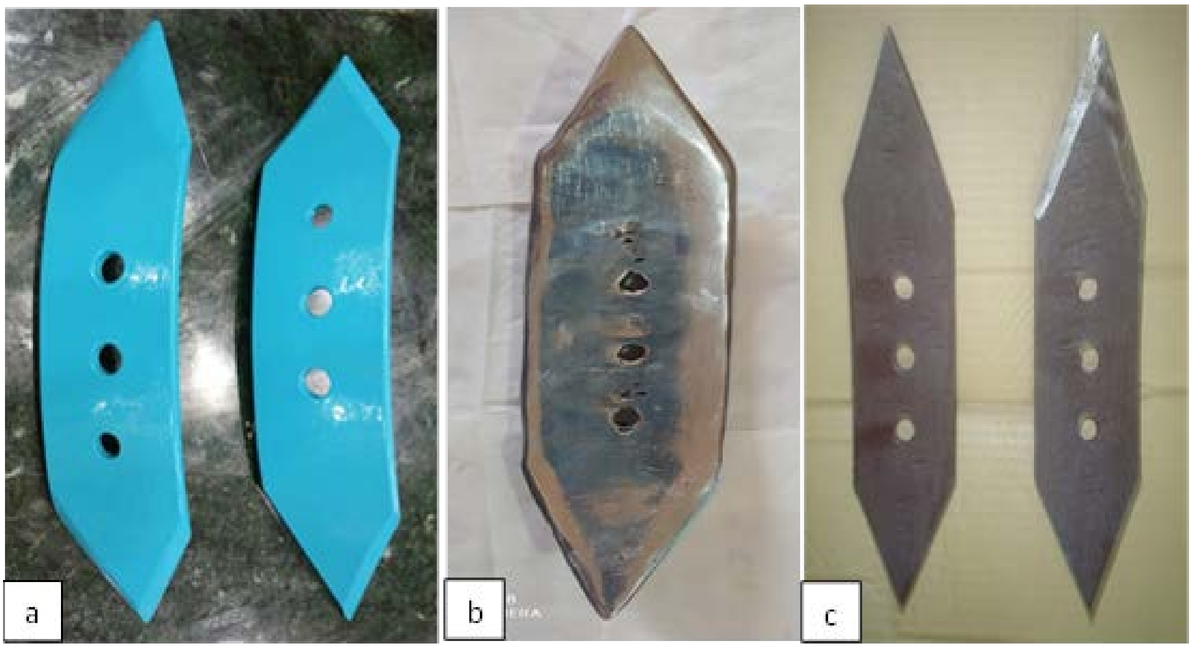


Figure 2 Different coating techniques applied for chisel shares (a) Hydrophobic and ceramic coating; (b) Nickel chrome plating; and (c) control (untreated chisel shares

2.3 Measurements and calculations

Weight before and after each time interval was noted with digital weighing balance displaying weight up to two places of decimal. Weight loss of chisel plough shares was calculated based on Equations 1 and 2:

$$\text{Weight loss, g} = \text{weight before wear test, g} - \text{weight after wear test, g} \quad (1)$$

$$\text{Weight loss, \%} = (\text{weight before wear test, g} - \text{weight after wear test, g}) / (\text{weight before wear test, g}) \times 100 \quad (2)$$

Size variation, variation in the width along the length of the blade after each time interval (dimensional wear) was got measured for determining the wear pattern. Variation in shares width of chisel plough was calculated based on Equations 3:

$$\text{Variation in shares width, mm} = \text{shares width before wear test, mm} - \text{shares width after wear test, mm} \quad (3)$$

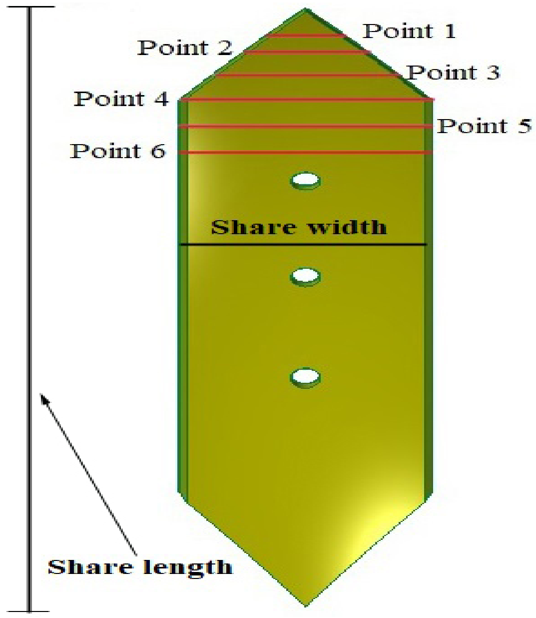


Figure 3 Dimensional wear measuring points with respect to width

A completely randomized design (CRD) of experiments was used for evaluating the coating techniques. Each observation was replicated thrice.

Dimensional wear was measured with respect to width. The length of blade was divided into divisions; the width was measured at each point along the length with the help of digital “Vernier Calliper” of least count 0.01 mm. The width was measured initially at 6 points (Figure 3) and successive measurements were noted after 40, 80, and 120 working hours. Control shares were made from carbon DIN C-45 steel (AISI 1045/ JIS S45C) without using any coating and were compared to shares treated with hydrophobic ceramic coating and nickel chrome plating. Spring dynamometer was used to measure the horizontal component of the drawbar pull (draught force) (El-Sheikha, 1989). This dynamometer was calibrated before starting the experiments and all experimented shares were operated at 0.7 m s^{-1} average speed.

3 Results and discussion

3.1 Effect of working hours and coating techniques on weight loss of chisel plough shares

Data ascertained that the amount of wear increased with time. Table 2 presents the effect of working hours and coating techniques on weight loss of chisel plough shares. Hydrophobic and ceramic coating gave weight loss of chisel plough shares by 0.49%, 3.46% and 4.64% when the plough shares operated for 40, 80, and 120 hours respectively. Shares treated with nickel chrome plating gave lowest weight loss values of 1.32%, 1.97%, and 3.17% with 40, 80, and 120 operation hours respectively. Control chisel shares gave heights weight loss values of 2.14%, 3.94%, 6.17% with 40, 80, and 120 operation hours respectively. Statistical analysis of the data showed significant variation of weight loss percentages among various weights at 5% level of significance. Average chisel share weight loss in grams under different coating techniques is presented in (Figure 4). It was clear that, in first working period of time, coating chisel shares with hydrophobic and ceramic coating gave more wear-resistant compared to shares that was treated by nickel chrome plating and control, however, this behaviour was changed during the longer operating hours, 80 and 120 h, where shares with nickel chrome plating gave lowest loss weight loss values.

Table 2 Effect of working hours and coating techniques on weight loss of chisel plough shares

Coating technique	Initial weight, (g)	After 40 h, (g)	Difference, (g) %age loss	After 80 h, (g)	Difference, (g) %age loss	After 120 h, (g)	Difference, (g) %age loss
Hydrophobic and ceramic coating	852.45	848.54	3.91 0.46	826.31	26.14 3.07	814.87	37.58 4.41
	842.54	837.71	4.83 0.57	805.94	36.60 4.34	801.78	40.76 4.84
	845.56	841.82	3.74 0.44	820.35	25.21 2.98	806.02	39.54 4.68
Average	846.85	842.69	4.16 0.49	720.68	29.32 3.46	807.56	39.29 4.64
Nickel chrome plating	966.32	957.53	8.79 0.91	949.54	16.78 1.74	937.71	28.61 2.96
	959.19	944.38	14.81 1.54	939.78	19.41 2.02	928.65	30.54 3.18
	947.85	933.58	14.27 1.51	927.34	20.51 2.16	916.02	31.83 3.36
Average	957.79	945.16	12.62 1.32	938.89	18.90 1.97	927.46	30.33 3.17
Control	796.25	779.35	16.90 2.12	764.6	31.65 3.97	742.15	54.10 6.79
	788.34	772.18	16.16 2.05	758.12	30.22 3.83	741.91	46.43 5.89
	790.47	772.68	17.79 2.25	758.85	31.62 4.00	744.50	45.97 5.82
Average	791.69	774.74	16.95 2.14	760.52	31.16 3.94	742.85	48.83 6.17

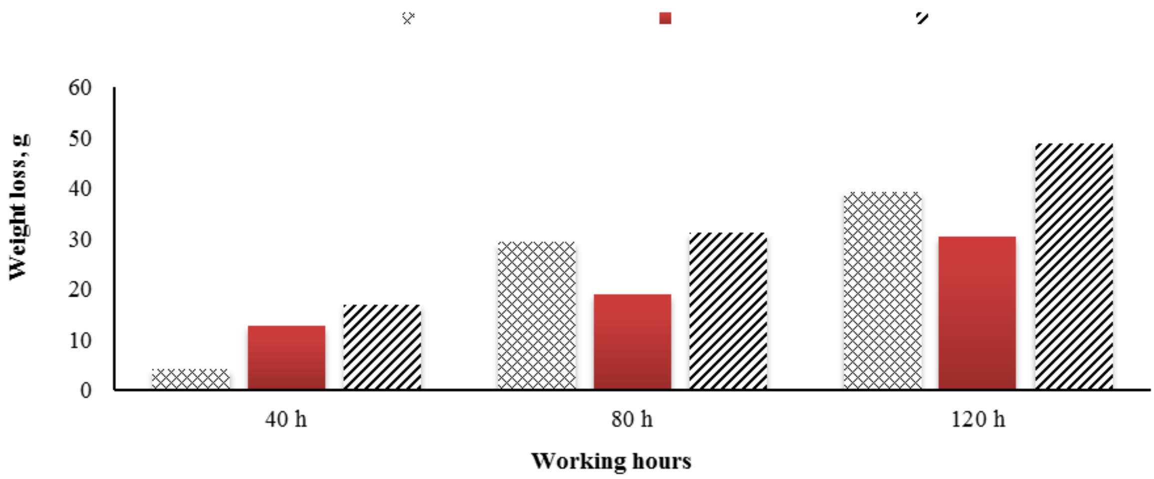
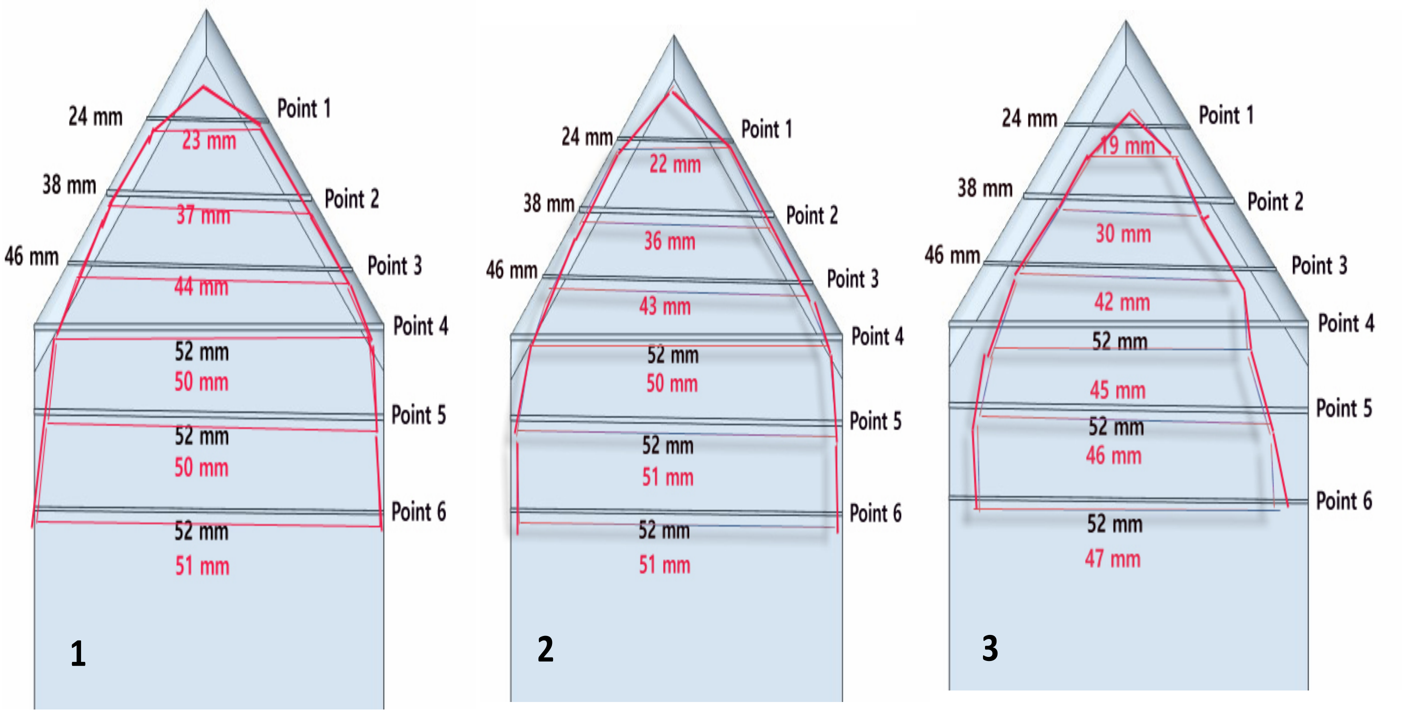


Figure 4 Average chisel share weight loss under different coating techniques



(1) hydrophobic and ceramic coated shares; (2) shares with Nickel chrome plating; and (3) control shares

Figure 5 differences in dimensions in mm located on chisel shares surfaces after 40 hours work

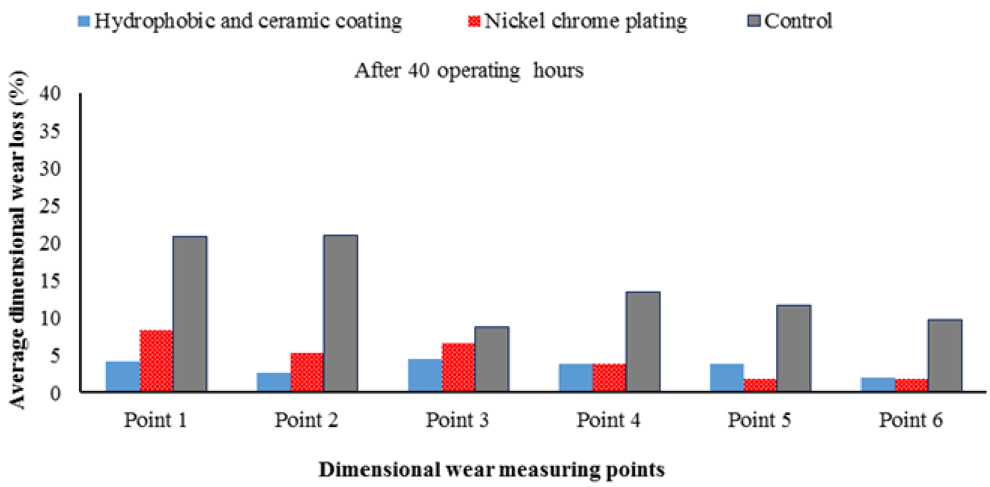


Figure 6 Average dimensional wear loss percentage under different coating techniques after 40 hours work

3.2 Effect of working hours and coating techniques on dimensional wear loss of chisel plough shares

After using chisel shares coated by hydrophobic and ceramic for 40 hours, the differences between original and final dimensions were 1, 1, 2, 2, 2 and 1 mm at points 1, 2, 3, 4, 5 and 6 respectively (Figure 5). Such changes in shares' dimensions produced average dimensional wear loss percentages of 4.17%, 2.63%, 4.35%, 3.85%, 3.85%, and 1.92% for same points from 1 to 6 respectively as in Figure 6. Chisel shares treated with nickel chrome plating gave higher differences in dimensions (2, 2, 3, 2, 1, and 1 mm) for measuring points 1 to 6 respectively. While, control shares gave the highest differences in dimensions (Figure 5). Same trend obtained for average dimensional wear loss percentages, where shares coated by hydrophobic and ceramic gave lowest dimensional wear loss percentages followed by shares treated with nickel chrome plating and control shares respectively (Figure 6).

Table 3 Dimensions differences and average dimensional wear loss percentages for different coating techniques after using chisel shares 80 hours

Coating technique	Measuring points on shares surfaces					
	Point 1	Point 2	Point 3	Point 4	Point 5	Point 6
	mm	mm	mm	mm	mm	mm
Hydrophobic and ceramic coating						
Original dimension, mm	24.00	38.00	46.00	52.00	52.00	52.00
Final dimension, mm	19	31	41	50	47	48
Difference, mm	5	7	5	2	5	4
% age decrease	20.83	18.42	10.87	3.85	9.62	7.69
Nickel chrome plating						
Original dimension, mm	24	38	46	52	52	52
Final dimension, mm	21	35	42	49	50	50
Difference, mm	3	3	4	3	2	2
% age decrease	12.50	7.89	8.70	5.77	3.85	3.85
Control						
Original dimension, mm	24	38	46	52	52	52
Final dimension, mm	16	30	39	43	43	41
Difference, mm	8	8	7	9	9	11
% age decrease	33.33	21.05	15.22	17.31	17.31	21.15

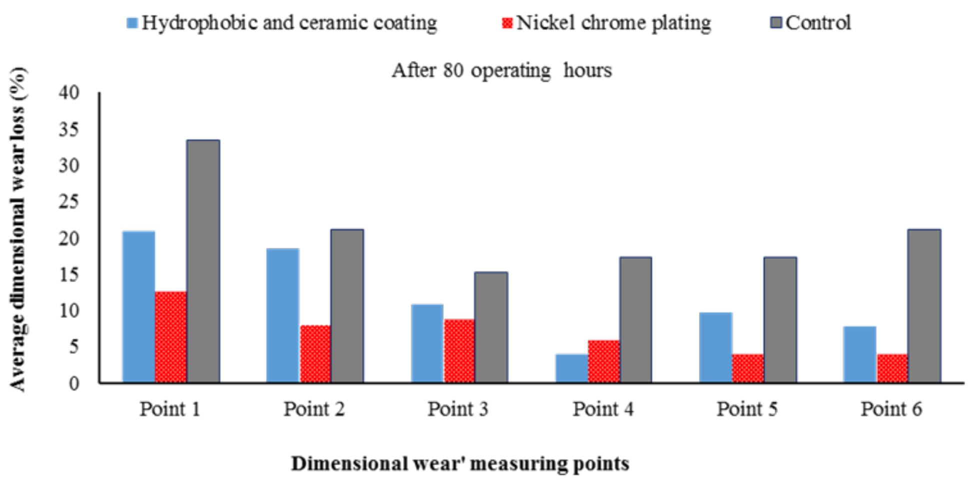


Figure 7 Average dimensional wear loss percentage under different coating techniques after 80 hours work

After using chisel shares for 80 hours, lowest differences in final dimensions obtained when using shares treated with nickel chrome plating followed by shares coated by hydrophobic and ceramic and then the control shares without treatments. Average differences between original and final dimensions were 3, 3, 4, 3, 2, 2 mm for shares treated with nickel chrome plating followed by 5, 7, 5, 2, 5, 4 mm dimension differences for shares coated by hydrophobic and ceramic. The highest dimensions differences recorded when using the control shares without any treatments and they were 8, 8, 7, 9, 9, 11 mm (Table 3). The same trend appeared for average dimensional wear loss percentages as in Figure 7

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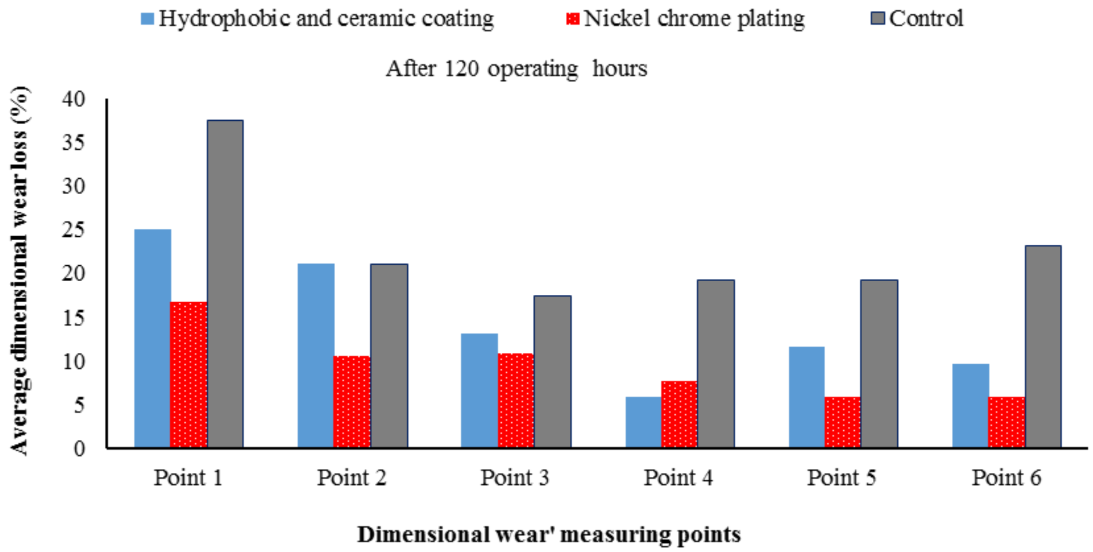

Figure 8 Average dimensional wear loss percentage under different coating techniques after 120 hours work

As it is ascertained that more working hours led to more wear in chisel shares. After 120 hours of using shares treated with nickel chrome plating, the value of average dimensional wear loss percentages were 16.67%, 10.53%, 10.87%, 7.69%, 5.77%, and 5.7%. With using shares coated by hydrophobic and ceramic, the average dimensional wear loss percentages were higher (25.00%, 21.05%, 13.04%, 5.77%, 11.54%, and 9.62%). While using the control shares, the average dimensional wear loss percentages recorded as highest values (Figure 8). The differences in dimensions before and after using the different shares are presented in Table 4 and have same trends as in average dimensional wear loss percentages. The overall effect of dimensional wear loss beside the wear weight loss in chisel shares was clear in the final shape of used chisel shares. Figure 9 shows the differences in shares' shape before wear test and after 80 hours operating time.

3.3 Effect of working hours and coating techniques on drawbar pull

Figure 10 shows different values of drawbar pull (draught force) measured during different working times for the shares treated with coating and plated compared to the control shares. Hydrophobic and ceramic coating material proved that it is very suitable to be used with shares but with shorter operating time, where, the average value of drawbar pull was 784.5 and 755.11 N at the begging and the ending of the first 40 working hours. Shares with nickel and chrome plating gave lower drawbar pull forces with longer operating hours. Control shares gave highest drawbar pull forces at all different operating times as shown in Figure 10.

3.4 Cost of treatments

Table 5 presents the total cost of coating a complete chisel plough 7-shares with hydrophobic and ceramic coating which is USD 11 (EGP 175). However, total cost of plating nickel chrome was USD 20 (EGP 315). Despite the low cost of using the nano technology, the shares performance was not the same as using nickel chrome plating at longer working hours and they deteriorated with higher rates. The difference in price was 44 % increase in cost to use nickel chrome plating, but the durability and long life achieved worth using the nickel chrome plating until testing better nanotechnology materials. Total price for the chisel share with coating materials also listed and it was USD 45 (EGP 715), USD 36 (EGP 575), and USD 25 (EGP 400) for shares plated with nickel chrome, shares coated with Hydrophobic & ceramic, and regular shares respectively.

Table 4 Dimensions differences and average dimensional wear loss percentages for different coating techniques after using chisel shares 120 hours

Coating technique	Measuring points on shares surfaces					
	Point 1	Point 2	Point 3	Point 4	Point 5	Point 6
	mm	mm	mm	mm	mm	mm
Hydrophobic and ceramic coating						
Original Dimension, mm	24.00	38.00	46.00	52.00	52.00	52.00
Final Dimension, mm	18	30	40	49	46	47
Difference, mm	6	8	6	3	6	5
% age decrease	25.00	21.05	13.04	5.77	11.54	9.62
Nickel chrome plating						
Original Dimension, mm	24	38	46	52	52	52
Final Dimension, mm	20	34	41	48	50	4950
Difference, mm	4	4	5	4	3	3
% age decrease	16.67	10.53	10.87	7.70	5.77	5.77
Control						
Original Dimension, mm	24	38	46	52	52	52
Final Dimension, mm	15	30	38	42	42	40
Difference, mm	9	8	8	10	10	12
% age decrease	37.5	21.05	17.39	19.23	19.23	23.08

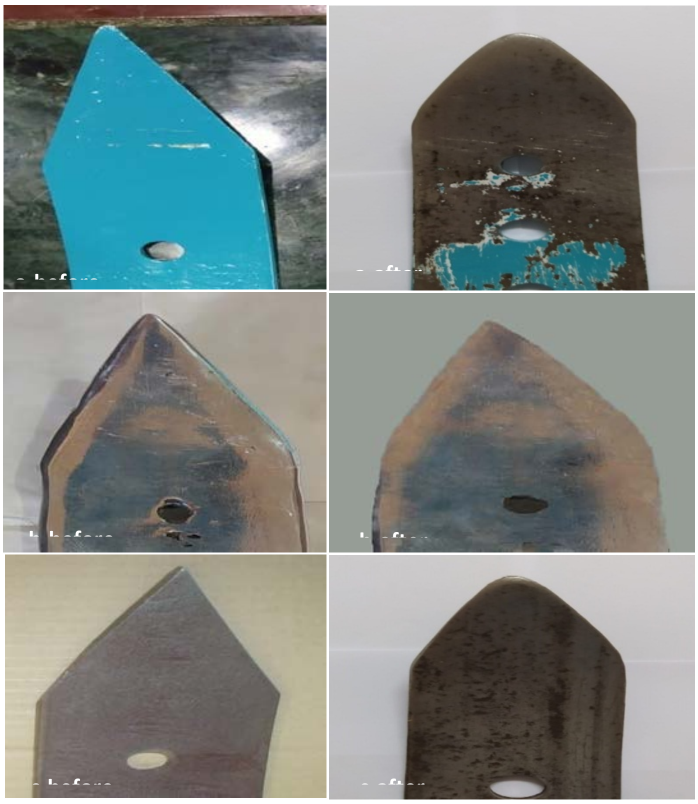

Figure 9 Differences in shares' shape before wear test and after 80 hours operating time. (a) Hydrophobic and ceramic coating; (b) Nickel chrome plating; and (c) control shares

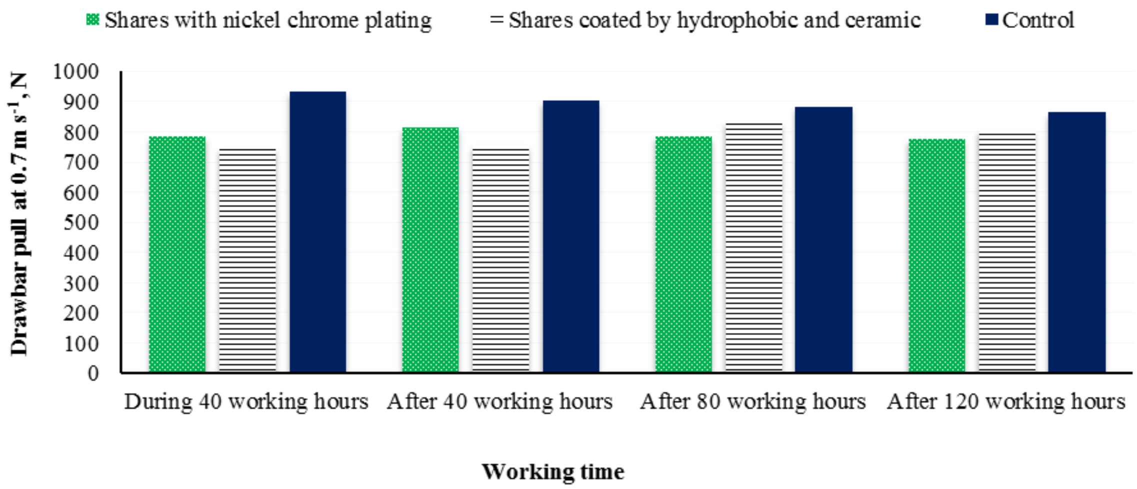

Figure 10 Effect of coating techniques on drawbar pull at different working hours and constant working speed of 0.7 m s^{-1}

Table 5 Total cost of different treatments applied to chisel shares

Coating technique	Cost for chisel share, USD (EGP)	Cost for chisel 7-shares plough, USD (EGP)	Cost for chisel 7-shares plough with coating USD (EGP)
Nickel chrome plating	2.8 (45)	20 (315)	45 (715)
Hydrophobic and ceramic coating	1.6 (25)	11 (175)	36 (575)
Control	0	0	25 (400)

4 Conclusion

Nickel chrome plating for chisel plough shares showed less wear than hydrophobic and ceramic coating with longer working hours. Both techniques showed less shares wear compared to shares without treatments. Best favorable worn-out behaviour in term of dimensions differences in mm during first 40 working hours was obtained using shares treated with hydrophobic and ceramic coating. It is not recommended to use the chisel plough shares without either coating or nickel chrome plating. The differences in price range for treated and untreated shares in not high and worth saving shares for longer working life than changing them frequently after wearing. Also, lower drawbar pull forces proved the advantages of using coated shares as low drawbar pull which is an indicator for lower fuel consumption and lower operational cost. Using nano technology as a coating techniques for agricultural tools still not common enough to be available in many places but it is promising process to protect farm tools such as plough shares and blades.

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Nomenclature

ADI: Austempered Ductile Iron

CaCO3: Calcium Carbonate

C-45 steel: carbon DIN C-45 medium steel (AISI 1045/ JIS S45C)

CRD: Completely Randomized Design of experiment

CSSP: The Center for Special Studies and Programs, Bibliotheca Alexandrina

EGP: Egyptian Pound

h: hour

SI14: 200 micron (0.2 mm) high density hydrophobic and ceramic coating

USD: United States Dollar