EGTRIB Journal
JOURNAL OF
THE EGYPTIAN SOCIETY OF TRIBOLOGY
VOLUME 17, No. 1, January 2020, pp. 27 - 35 ISSN 2090 - 5882
(Received November 02. 2019, Accepted in final form December 05. 2019) www.egtribjournal.com

MECHANICAL AND TRIBOLOGICAL PROPERTIES OF COATED STEEL BLANKING PUNCH

Ramadan M. K., Lashin M. M. A. and Gaafer A. M.

Mechanical Engineering Department, Faculty of Engineering at Shoubra, Benha University, Cairo, Egypt.

ABSTRACT
The present work aims to improve tool life of blanking punches by physical vapor deposition (PVD) coatings. TiN, TiCN, TiAlN and CrN coatings were tested. Hardness, wear and fatigue tests were carried out. Coatings were deposited on the surfaces of blanking punches that were hardened to have 60-62 HRC hardness, then groud to have 0.4 µm Ra surface roughness. The punches were tested by A10 washer stamp. The test results revealed that, TiAlN coated punch showed the highest hardness values, lowest wear rate and longer fatigue life. Besides, TiAlN coated punch showed the highest wear resistance. A mathematical model was introduced to correlate hardness, wear and fatigue of the tested punches. An agreement between values derived from the mathematical model and the experimental results was found.

KEYWORDS
Hardness, Wear, Fatigue, Coating, Blanking Punch.

INTRODUCTION
Blanking of steel sheets is extensively applied in the automotive industry. It is necessary to develop the wear resistance of the surface of the punch, [1, 2]. The quality of blanked parts is strongly affected by the wear of the tool, punch and die, [3]. Wear of the tool increases the exerted force and decreases the tool life. Besides, increase of clearance between the punch and die damages the quality of the parts surface, [4]. There is an increasing demand to coat the surfaces of the tool to reduce wear, [5]. Physical vapor deposition (PVD) process is applied to coat the surfaces of the tool, [6]. The highest tool purity can be obtained by PVD coating technique due to low pressures, [7, 8]. The PVD coating of the punch with a surface layer of improved hardness and low friction may reduce wear.

Wear resistance of AlCrN coatings was investigated, [9]. The results were compared to uncoated punches under the same operating conditions. The and compared with the wear resistance of uncoated punching tools. Wear observed for the cutting edge of the punch was reduced by AlCrN coatings. TiAIN and AlCrN coatings were tested, [10, 11]. Examination of the worn surface of the tested coatings by scanning electron microscope

(SEM) showed that abrasion and adhesion were the major wear mechanisms that deformed plastically the punch cutting edge. AlCrN coatings showed promising results than TiAlN coatings.

In the present work, four types of coating material TiN, TiCN, TiAlN and CrN were applied to coat steel punch to investigate their performance to increase fatigue life, hardness and decrease wear. A mathematical model was introduced based on the experimental results.

EXPERIMENTAL

X155CrMoV12 cold work tool steel was used as punch material, while St. 37 was used as work piece. Blanking punches were hardened and tempered, where the hardness was 60 - 62 HRC. The surface roughness was Ra = 0.4. Ion plating process was applied to deposit the coating layers, Fig. 1, where the substrate material was vaporized and bombarded by high-energy gas ions.

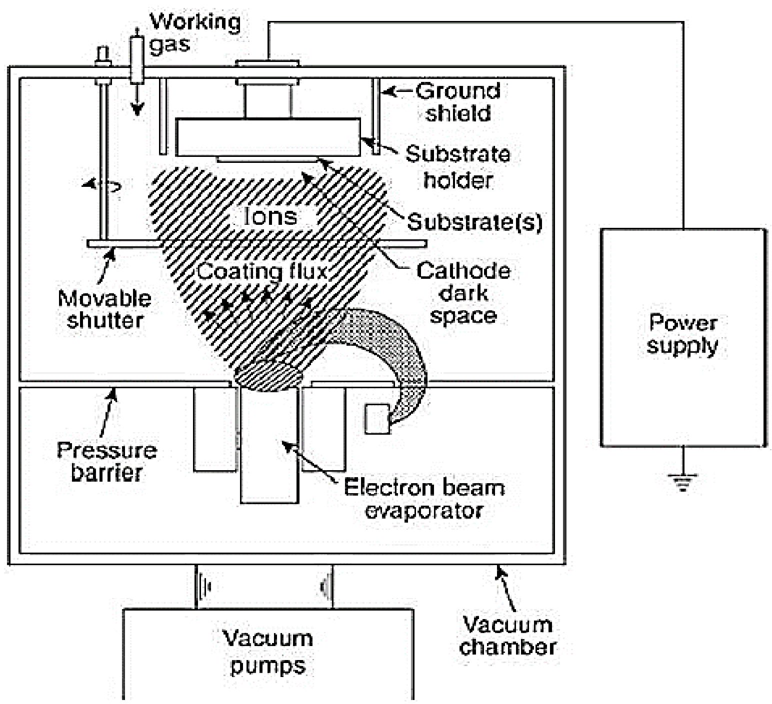

Fig. 1 Ion Plating Process.

The coating materials were TiN (Titanium Nitride), TiCN (Titanium Carbon Nitride), TiAlN (Titanium Aluminum Nitride) and CrN (chromium Nitride) deposited through LD-600A PVD coating machine. The specification of the coating materials is shown in Table 1.

Table 1: Coatings Materials Characteristics

Coating	TiN	TiCN	TiAlN	CrN
Thickness (μm)	3	3	3	3
Color	Gold	Silver - Gray	Black	Silver
Temperature (C°)	500	400	700	500

Examination of microstructure, hardness, wear, fatigue and tensile tests were carried out according to ASTM- A892, [12]. Chemical etchant (3 %NTAL + 97 % Alcohol) was used to prepare the examined surfaces. The measurement of the micro-hardness of coated surface was carried out according to ASTM-E384, [13]. Pin-on-disk (ASTM-G99), [14], was used determine wear. The pin was coated cylinder of 7.8 mm diameter, where the load was 200 N and the disc rotated by 200 r.p.m for 15 minutes. The fatigue test was performed according to ASTM-E466, [15], at 500 N applied load. For every punch, steel (A10) washer stamp was used using hydraulic press, where 10000 blanking processes were done.

RESULTS AND DISCUSSION

The microstructures of the punches coating layer and substrate material are showing in Fig. 2.

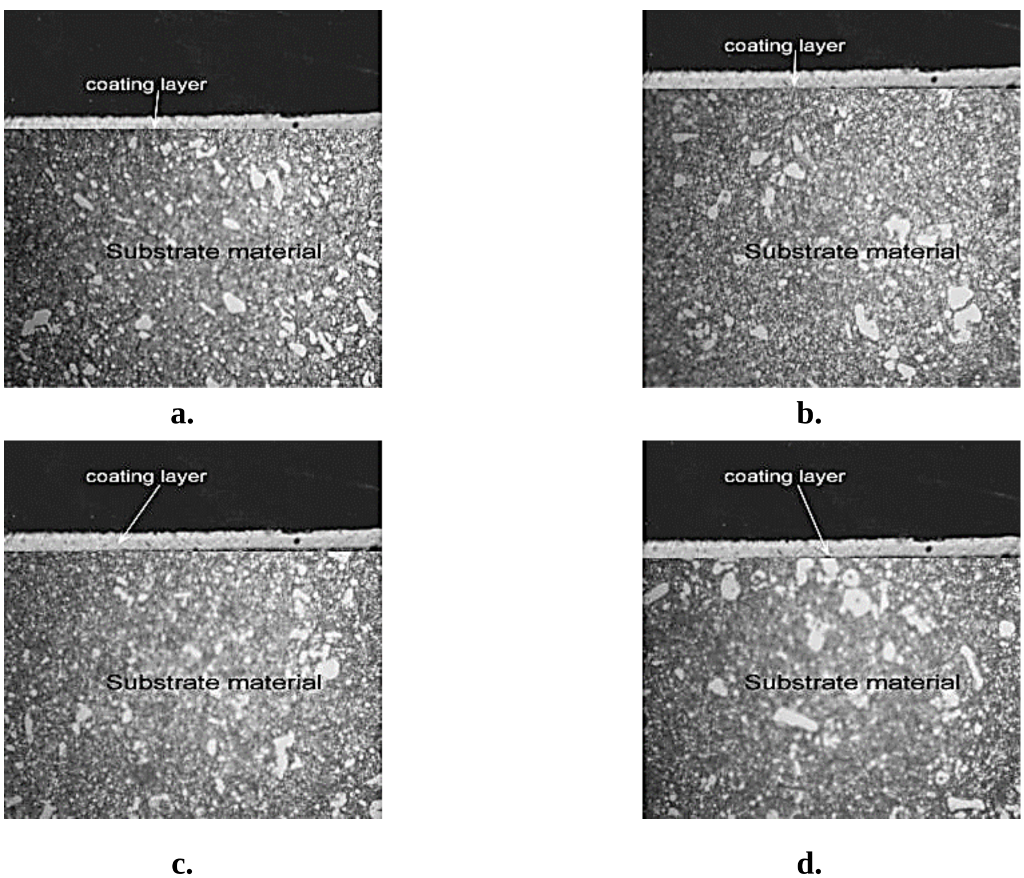

Fig. 2 Microstructure of the tested Punches (X1000), (a) TiN Coated Punch, (b)TiCN Coated Punch, (c)TiAlN Coated Punch, and (d) CrN Coated Punch.

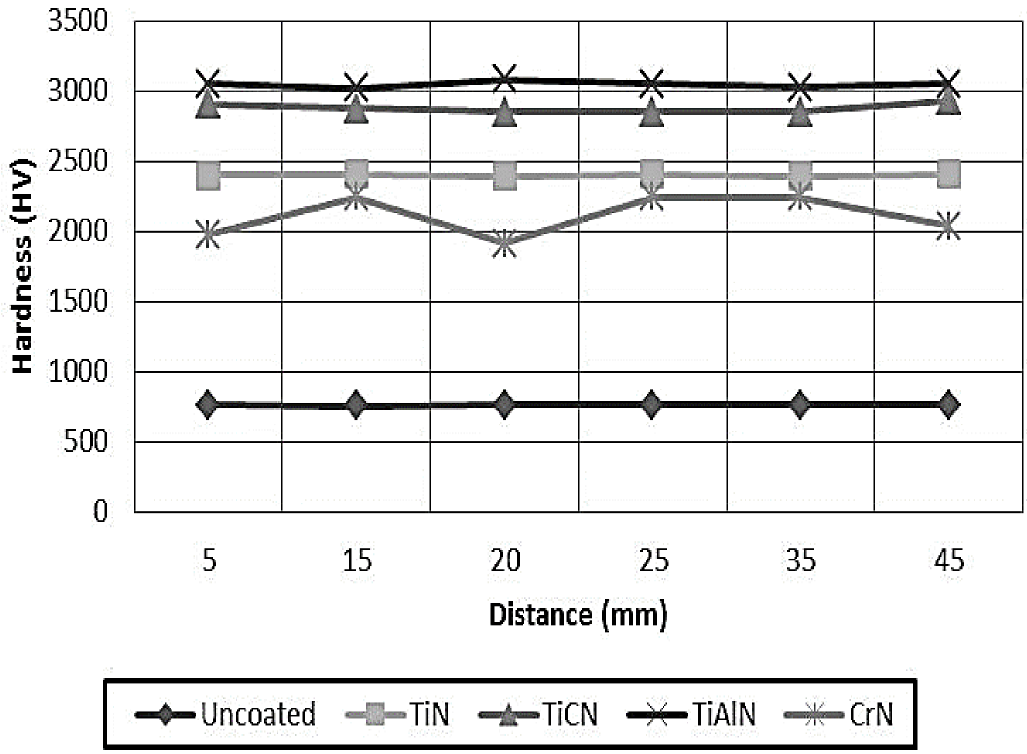

Fig. 3 Vickers Hardness of the tested surfaces.

The photomicrographs show the microstructure of the tested coatings, where the thickness of coating is equal for all the tested punches, homogeneous and well adhered to the substrate. The measurement of the Vickers hardness of the punches versus distance from edge of punch is shown in Fig. 3. The TiAlN coated punch showed the highest hardness (3044 HV). The uncoated punch has the lowest hardness (764 HV). This behavior can be attributed to the presence of iron carbide, iron nitride, molybdenum carbide and titanium aluminum nitride in TiAlN coated punch. Wear measured by weight for the tested coatings is shown in Fig. 4. It is clearly seen that TiAlN coated punch has the lowest wear, while the uncoated punch exhibited the highest wear value.

Figure 5 shows the alternating stress amplitude versus number of cycles to failure (S-N curve) for the tested punches. TiAlN coated punch displayed the highest number of cycles to failure that reached to 1.5×10^6 cycles while the uncoated punch has the lowest number of cycles to failure that approached 0.5×10^6 cycles. The weight loss of the tested punches after blanking is shown in Table 2, while wear values of the tested coated punches are shown in Fig. 6. TiAlN coating displayed the lowest wear (0.50 g), while uncoated punch showed the highest wear (1.50 g). It was observed that the coated punches gave lower noise during the blanking than that observed for uncoated one, where TiAlN coated punch was the favorite one.

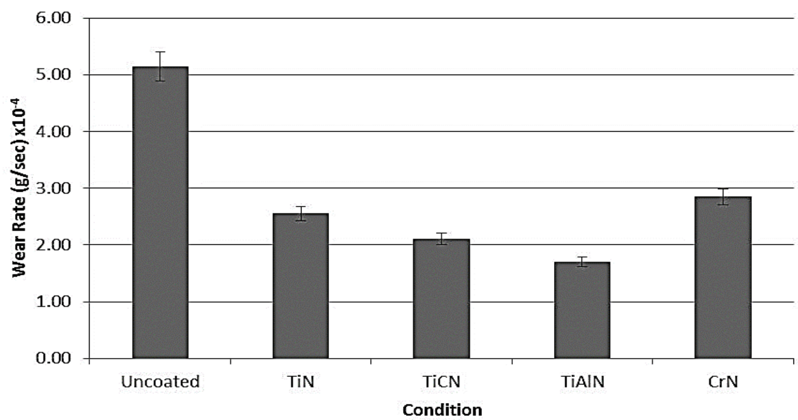

Fig. 4 Wear of the tested Punches.

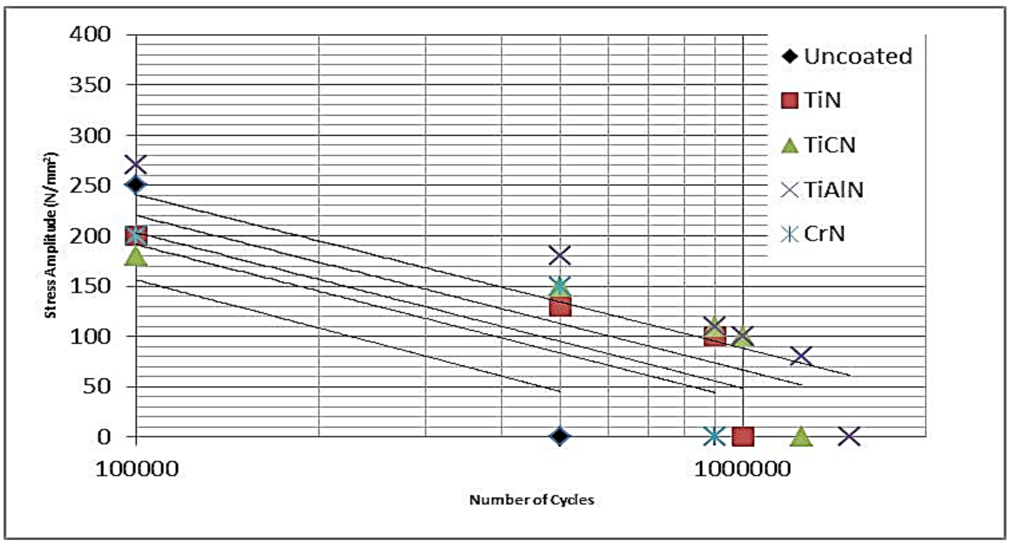

Fig. 5 S-N Curve of the tested Punches.

Table 2. Weight Loss of the tested punches after Blanking Process.

Condition	Weight (g)		Weight Loss(g)
	Before	After	
Uncoated	115.50	114.00	1.50
TiN	115.50	114.80	0.70
TiCN	115.60	115.00	0.60
TiAlN	115.70	115.20	0.50
CrN	115.60	114.80	0.80

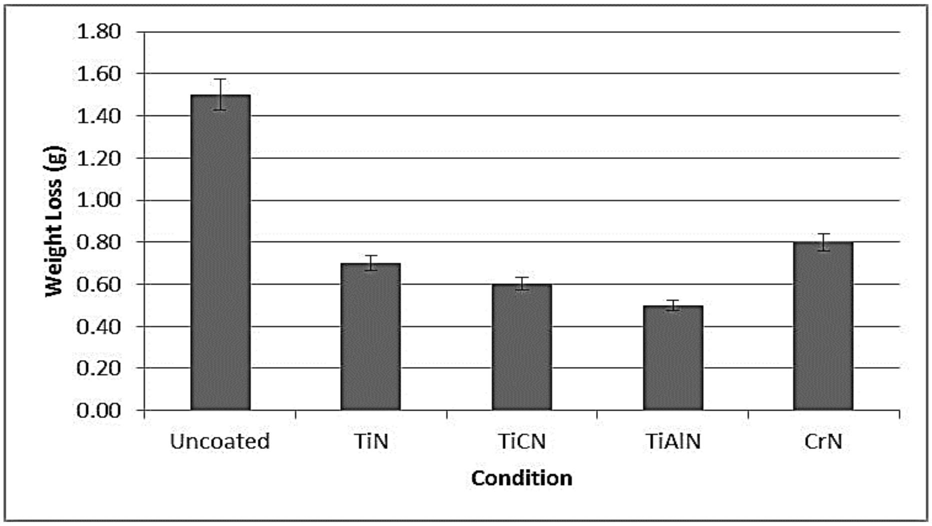

Fig. 6 Weight loss of the tested punches after blanking.

The experimental results carried out in the present work for coated and uncoated punches are shown in Table 3. It is shown that the hardness of TiAIN represented the highest values among the other coating materials due to the relatively higher content of titanium and molybdenum carbide in the TiAlN coated punch. The hardness increase decreased the wear.

Table 3. Tests Values for Coated and Uncoated Punches

Punch Condition	Tests		
	Hardness (HV)	Wear Rate (gm/s)	Fatigue (No. of cycles to failure)
Uncoated	764	$5.11x10^{-4}$	500000
TiN	2401	$2.78x10^{-4}$	1000000
TiCN	2879	$2.22x10^{-4}$	1250000
TiAIN	3044	$1.89x10^{-4}$	1500000
CrN	2112	$2.89x10^{-4}$	900000

In addition, TiAlN punch coated material gained the highest number of cycles to failure compared to the other coatings.

The chemical analysis was carried to determine the contents of the compounds in the coatings using XRD (X-Ray Diffraction). The contents of the compounds are shown in Table 4, where increasing contents of iron carbide (Fe_3C), and molybdenum carbide (Mo_2C) increased hardness, [16 - 17].

Table 4. X-Ray Diffraction Analysis of Coated and Uncoated Punches.

Compound	Uncoated	TiN Coating (37% Titanium Nitride)	TiCN Coating (30% Titanium Carbon Nitride)	TiAlN Coating (25%Titanium Aluminum Nitride)	CrN Coating (37% Chromium Nitride)
Fe_3C (Iron Carbide)	49%	13%	18%	29%	28%
Mo_2C (Molybdenum Carbide)	6%	9%	13%	16%	8%
-Fe (Ferrite)	45%	7%	12%	8%	22%
Fe_2N (Iron Nitrate)	--------	34%	27%	22%	5%

As seen from analysis of XRD the tested coating TiAIN owned the highest values of Fe_3C, and Mo_2C. Increasing the iron nitrate Fe_2N and decreasing ferrite -Fe content increased hardness, fatigue life and wear resistance. The table values confirmed that TiAIN had the best performance among the others coatings.

Mathematical Modeling

The correlation between mechanical properties (hardness, wear and fatigue) with chemical composition of the tested PVD coatings, Minitab 17 package (Statistical software for analysis in statistics and econometrics) was used, [18], as follows:

$$\text{Hardness} = 2495 - 40.63\, Fe_3C + 146.8\, Mo_2C - 13.79\, \alpha\text{-}Fe - 23.25\, Fe_2N$$

$$\text{Wear} = 0.000136 + 0.000005\, Fe_3C - 0.000016\, Mo_2C + 0.000005\, \alpha\text{-}Fe + 0.000005\, Fe_2N$$

$$\text{Fatigue} = 673625 - 2365\, Fe_3C + 68804\, Mo_2C - 10457\, \alpha\text{-}Fe - 5556\, Fe_2N$$

The values of hardness, wear and fatigue number of cycles extracted from Minitab 17 are shown in Table 5.

Table 5. Minitab 17 Software Analysis Data.

Mechanical Properties	Uncoated Punch	TiN Punch Coated (37% Titanium Nitride)	TiCN Punch Coated (30% Titanium Carbon Nitride)	TiAlN Punch Coated (25%Titanium Aluminum Nitride)	CrN Punch Coated (37% Chromium Nitride)
Hardness	2477.638	2494.0598	2498.8383	2500.4871	2491.4471
Wear Rate	$1.3974\text{x}10^{-4}$	$1.3386\ \text{x}10^{-4}$	$1.3407\ \text{x}10^{-4}$	$1.3419\ \text{x}10^{-4}$	$1.3697\ \text{x}10^{-4}$
No. of Cycles (Fatigue)	671888.74	676888.88	679388.86	681888.91	675888.78

CONCLUSIONS

1. TiAlN coating showed the highest value of hardness (3044 Hv), while the uncoated surface displayed the lowest value (764 Hv).

2. The lowest wear was displayed by TiAlN coating.

3. TiAlN coatings displayed the highest number of cycles to failure (1500000 cycles).

4. Values derived from the mathematical model shows an agreement with the experimental results, where TiAIN coating have the best values among the other types of coated punch materials.

REFERENCES

1. Hambli R., " BLANKSFT, A Code for Sheet Metal Blanking Processes Optimization", J. Mater Processes Technology, No.141, Pp 234 - 242, (2003).

2. Monteil G, Greban F., Roizard X., " In situ Punch Wear Measurement in a Blanking Tool by Means of Thin Layer Activation", Wear, No. 265, pp. 626 - 633, (2006).

3. Hernandez J. J., Franco P., Estrems M., Faura F., " Modelling and Experimental Anaylsis of the Effects of Tool Wear on Form Errors in Stainless Steel Blanking', J. Mater Processes Technology, No. 180, pp. 143 - 150, (2006).

4. Ivana S., Handbook of Die Design (second edition), McGraw-Hill, (2006).

5. Jeffrey A. Hopwood, Ionized Physical Vapor Deposition, Academic Press, (2000).

6. Noor M. M., Daud R., Kadirgama K., Rejab M. R. M., "Development of Turret Punch Cutting Tool Using Reverse Engineering Method",National Conference on Design and Concurrent Engineering, Product Innovation, Reverse Engineering & Rapid Prototyping, (2009).

7. Donald M. M., "Handbook of Physical Vapor Deposition (PVD) Processing", William Andrew is an imprint of Elsevier William Andrew is an imprint of Elsevier, second edition, (2005).

8. Liina L., Priidu P., "Wear of Different PVD Coatings at Industrial Fine-blanking Field Tests", Material Science, Vol. 21, No. X, pp. 332 – 345, (2015).

9. Çöl M., Kir D., Erişir E., "Wear and Blanking Performance of AlCrN PVD-Coated Punches", Materials Science, Vol. 48, No. 4, January, pp. 32 – 38, (2013).

10. Erisir E., Col M., Kir D., "Investigations on Wear of PVD Coated Punches for Sheet Steel Blanking", 3rd International Conference of EngineeringAgainst Failure, (2013).

11. Mertin P. M., Handbook of Deposition Technologies for Films and Coatings (second edition), Elsevier Inc, (2005).

12. ASM Handbook Volume 5, "Surface Engineering", ASM International, (1994).

13. ASTM, A 892 – 88, Standard Guide for Defining and Rating the Microstructure of High Carbon Bearing Steels, ASTM International, (2004).

14. ASTM, E 384 – 99, Standard Test Method for Microindentation Hardness of Materials, ASTM International, (2004).

15. ASTM G 99 – 04, Standard Test Method for Wear Testing with a Pin-on-Disk Apparatus, ASTM International, (2004).

16. ASTM E 8M – 04, Standard Test Methods for Tension Testing of Metallic Materials [Metric], ASTM International, (2004).

17. Iron-Carbon Phase Diagram, MSE 300 Materials Laboratory Procedures, University of Tennessee, Dept. of Materials Science and Engineering, (2008).

18. Wang X. R., Yany M. F. and Chen H.T., "First-Principle Calculations of Hardness and Melting Point of Mo2C", J. Mater. Sci. Technol., Vol. 25 No. 3, pp. 254 – 267, (2009).
19. Handanbaycik M., "The Study of Phase Structures and Surface Hardness Values of Ion Nitride AISI H13 Steel Under Various Temperatures", Technology, 12(2), pp. 79 - 86, (2009).
20. Getting Started with Minitab 17, by Minitab Inc. 2014, (2016).