# A COMPARISON OF FRICTION CHARACTERISTICS OF VARIOUS SURFACE TREATED HOT WORK TOOL STEEL

Phd Student Tutar M.[1], Prof. Dr. Bayram A.[1]
Faculty of Engineering – Mechanical Engineering Department –Uludağ University, Turkey [1]
mumintutar@uludag.edu.tr

***Abstract:*** *Wear, is one of the most important failure type which reduces the service lifetime and increases the maintenance cost of machines. In addition, wear is directly related with surface properties and friction characteristics. So, researchers focus on various surface treatments to reduce the wear and its cost. Plasma nitriding is one of surface treatment which forms a few hundred micron diffusion zone and a surface inter-metallic phases with moderate surface hardness. PVD coating is another method which ensures ultra-hard and a few micron surface layers. In the present study, AISI H13 hot work tool steel substrate was surface treated with various methods, such as plasma nitriding, PVD coating and duplex treatment. Effects of the treatments on the surface roughness, hardness were investigated. Additionally, microstructural analysis was performed to present the effect of treatments on the surface microstructures. Furthermore, friction characteristics were investigated using ball on disk testing machine and wear tracks were discussed using optical microscopy.*

**Keywords**: PLASMA NITRIDING, PVD COATING, DUPLEX TREATMENT, FRICTION

## 1. Introduction

Wear, is one of the most important factor that effects the service lifetime, occurs due to relative motion of contacting components. Plasma nitriding (PN) and physical vapour deposition (PVD) are mostly used to enhance the wear resistant of steels. While the PN forms different zones (white zone, nitriding zone) which are very thick compared to PVD, the PVD forms only a few microns thick layer, which is harder than PN, on the surface of steel. PVD coating on a relatively soft base material causes an inconsistency related with hardness values. Therefore, to form a transition zone makes the service time longer. These techniques have some advantages/disadvantages on each other. So, application of these techniques together is a way to eliminate the disadvantages of each [1–5]

In this study, PN and PVD applied on AISI H13 steel with different combinations. Friction characteristics were obtained via ball on disk test. Effect of the surface treatments on surface hardness also measured. Additionally, microstructural examinations and microhardness measurement were performed

## 2. Material and Method

The chemical composition of AISI H13 steel used as base material can be seen in Table 1. Prior to all surface treatments as-received steel was heat treated using the schedule given in Fig. 1. PN parameters were given in Table 2. Two different PVD coatings were selected and application was made by Oerlikon Balzers and Ionbond Tinkap. Information about PVD coating were presented in Table 3. Nomenclature of the samples produced using different treatments were given in Table 4.

***Table 1.*** *Chemical composition of hot work tool steel used in this study*

| *DIN* | *AISI* | *C* | *Si* | *Mn* | *Cr* | *Mo* | *V* |
|---|---|---|---|---|---|---|---|
| **1.2344** | H13 | 0,39 | 1,00 | 0,40 | 5,30 | 1,40 | 0,90 |

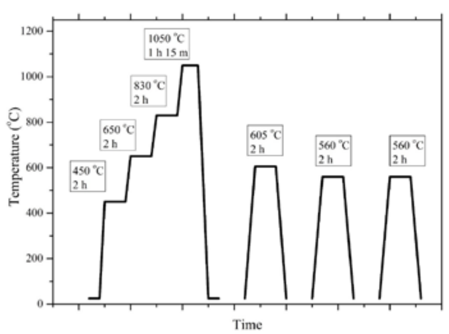


***Fig. 1.*** *Tempering heat treatment schedule*

***Table. 2.*** *PN parameters*

| *Temperature* | *Time* | *Gas Ratios* | *Pressure* |
|---|---|---|---|
| 500 °C | 10 h | $H_2/N_2$ (¼) | 250 Pa |

***Table. 3.*** *PVD coatings*

| | *Coating thickness(μm)* | *Friction coefficient* | *Micro hardness (HV)* | *Coating color* |
|---|---|---|---|---|
| **Ionbond (CrN)** | 1-4 | 0,40 | 2400-2600 | Silver |
| **Oerlikon Balzers (TiAlN)** | depend on the application | 0,30-0,35 | 3300 | Purple-Gray |

***Table. 4.*** *Nomenclature of samples*

| *Specimen* | *Treatment* |
|---|---|
| S00 | As received |
| S10 | Tempered |
| S11 | Tempered + PVD (CrN) |
| S12 | Tempered + PVD (TiAlN) |
| S20 | Tempered + PN |
| S21 | Tempered + PN + PVD (CrN) |
| S22 | Tempered + PN + PVD (TiAlN) |

To reveal the effect of PN on surface roughness, all samples were polished after tempering to obtain a certain surface roughness. Surface polishing was also carried out before PVD coating to enhance the bonding capability of PVD layer. Samples were analyzed optically for microstructural changes and possible defects using a Nikon DIC microscope with a Clemex image. Vickers microhardness measurements were performed on a DUROLINE-M microhardness tester. Ball on disk testing machine was used to compare friction characteristics of different treatments. Friction speed and load were 4.45 mm/s and 5.82 N, respectively. Maximum and mean Hertz contact pressure was calculated as 1.76 GPa and 1.16 GPa, respectively.

## 3. Result and Discussion

Surface roughness of different heat treated samples were measured and given in Fig. 2. While PN and CrN PVD coating on tempered sample decreased the surface roughness slightly, PVD TiAlN coating increased. Similar to this findings, the difference of the surface roughness of CrN and TiAlN coating was reported by Björk et al.[6]. Although Batista et al. [7] reported that duplex coating occurred higher surface roughness, in the present study, no important difference was observed. It can be related with polishing procedure after PN. In addition, duplex treatment increased the surface hardness in both case.

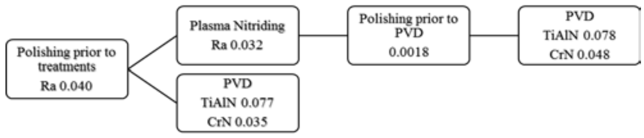


***Figure 2.*** *Surface roughness of samples*

All obtained microstructures can be seen in Fig 3. As tempered sample contained martensitic microstructure with carbides of elements such as Cr, Mo and V. Plasma nitrided samples shows different zones including white zone and nitrided transition zone. Diffusion zone measured as 100 µm roughly. CrN PVD coating formed 1-2 µm thick non-uniform layer, while TiAlN PVD coating formed 3-5 µm thick uniform layer. It should also be noted that TiAlN PVD coating had a interlayer to enhance the adherence on coating layer on substrate.

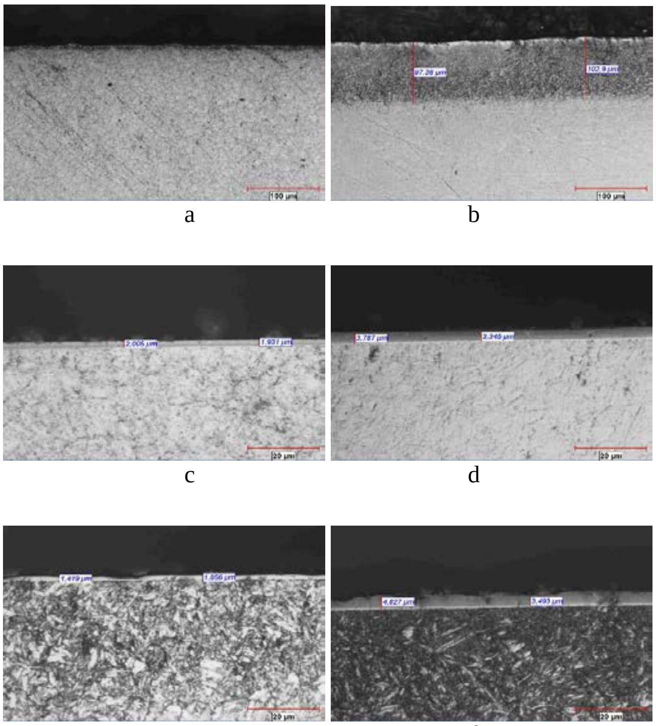


***Figure 3.*** *Obtained microstructures of samples a)S10 b)S20 c)S11 d)S12 e)S21 f)S22*

The surface hardness values of the investigated samples are presented in Fig. 4. It can be seen that the untreated sample had a hardness of 227 $HV_{0.025}$. The surface hardness of the tempered sample reached 616 $HV_{0.025}$ because of the formation of tempered martensite. The micro hardness profile of plasma nitrided sample shown in Fig.5. The combination of tempering and plasma nitriding processes increased the surface hardness of the untreated material to 1059 $HV_{0.025}$, as a result of the formation of the compound layer containing extremely hard iron nitrides. According to DIN 50 190/3, nitriding depth defined as the depth which shows 50 HV higher hardness that base metal. The nitriding depth calculated as 160 µm. The surface hardness of the TiAlN coating on the plasma nitrided layer reached 3320 $HV_{0.025}$, which was approximately around 15 times that of the untreated substrate and 3 times that of the plasma nitrided layer. Similarly, the surface hardness of the CrN coating on the plasma nitrided layer showed a significant increase (2424 $HV_{0.025}$), specifically, approximately 11 times that of the untreated substrate and 2 times that of the plasma nitrided layer.

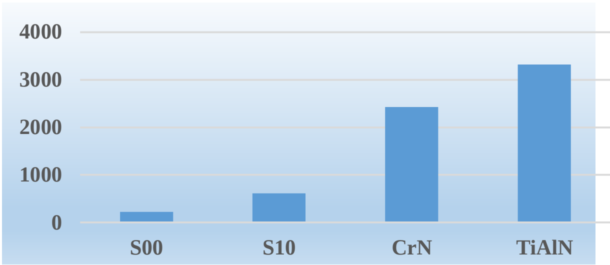


***Figure 4.*** *Microhardness values of samples*

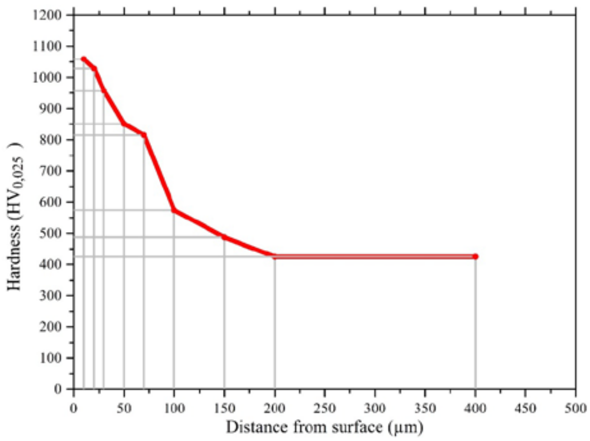


***Figure 5.*** *Microhardness profile of plasma nitrided sample*

Friction coefficient change versus distance can be seen in Fig. 6. Friction coefficient values starts from a specific value related with surface conditions created by heat treatment. After a while, due to activated wear mechanisms (abrasive and fatigue wear in this study) friction coefficients increased and reached a specific value. PVD coated samples exhibited better performance than plasma nitrided sample, while duplex treated samples showed the best performance. TiAlN PVD coated samples exhibited superior behavior over CrN PVD coated samples. Taktak et al. [8] reported that PN decreased the friction coefficient. Additionally, as can be seen from the change of friction coefficient graphs, applied load did not crack the coating layers when the load placed on the sample. Wear track was formed by wear mechanisms.

Optical micrographs of wear tracks were presented in Fig. 6. The width of the wear tracks are in accordance with friction characteristics. The mostly worn sample, as can be easily predict, was tempered one. While, plasma nitrided sample shows excessive wear, PVD coated and duplex treated samples show almost no wear.

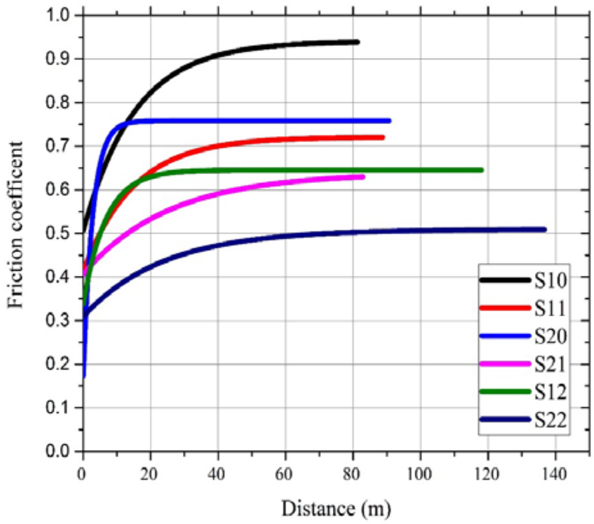


***Figure 5.*** *Friction coefficients of tested samples*

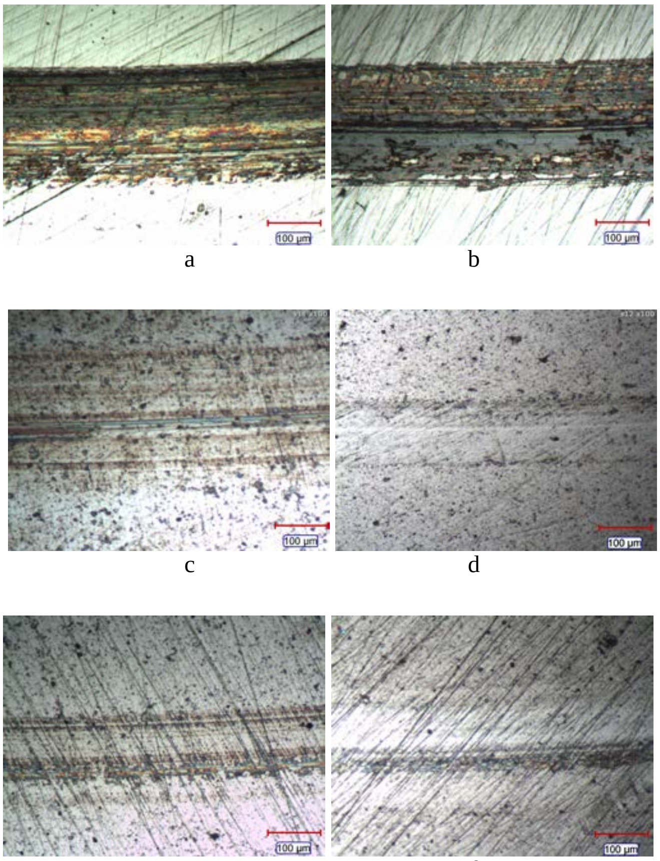


***Figure 7.*** *Optical micrographs of wear track of samples a)S10 b)S20 c)S11 d)S12 e)S21 f)S22*

## 4. Conclusion

The present study was focused on the friction characteristics of AISI H13 tool steels treated with duplex treatmens. From this investigation, the following conclusions can be derived.

- The use of a plasma nitriding process on the tempered H13 steel increased its surface hardness to approximately 4.7 times that of the untreated substrates and approximately 1.8 times that of the tempered samples.
- The use of a plasma nitriding process prior to PVD coating played an important role in the increase of the surface hardness. Surface hardness of the TiAlN-coated sample was approximately 15 times higher than that of the untreated substrates and approximately 3 times than that of the plasma nitrided layers. However, the surface hardness of the CrN-coated sample was approximately 11 times higher than that of the untreated substrates and approximately 2 times greater than that of the plasma nitrided layers.
- PN enhanced friction properties of tempered steel while PVD coated samples exhibited better performance than plasma nitrided samples.
- TiAlN PVD duplex treatment exhibited the best performance among all treatments.

## 5. References

[1] M. Tutar, H. Aydin, A. Durmus, A. Bayram, K. Yigit, The hydro-abrasive erosion wear behavior of duplex-treated surfaces of AISI H13 tool steel, Sci. China Technol. Sci. 57 (2014) 1040–1051. doi:10.1007/s11431-014-5510-8.

[2] A. Chala, C. Nouveau, M.A. Djouadi, P. Steyer, J.P. Millet, C. Saied, et al., Effect of duplex treatments by plasma nitriding and triode sputtering on corrosion behaviour of 32CDV13 low alloy steel, Surf. Coatings Technol. 200 (2006) 6568–6571. doi:10.1016/j.surfcoat.2005.11.036.

[3] O. Durst, J. Ellermeier, C. Berger, Influence of plasma-nitriding and surface roughness on the wear and corrosion resistance of thin films (PVD/PECVD), Surf. Coatings Technol. 203 (2008) 848–854. doi:10.1016/j.surfcoat.2008.05.022.

[4] F. Mahboubi, M. Fattah, Duplex treatment of plasma nitriding and plasma oxidation of plain carbon steel, Vacuum. 79 (2005) 1–6. doi:10.1016/j.vacuum.2005.01.002.

[5] T. Björk, R. Westergård, S. Hogmark, Wear of surface treated dies for aluminium extrusion — a case study, Wear. 249 (2001) 316–323. doi:10.1016/S0043-1648(01)00550-6.

[6] T. Björk, R. Westergård, S. Hogmark, J. Bergström, P. Hedenqvist, Physical vapour deposition duplex coatings for aluminium extrusion dies, Wear. 225-229 (1999) 1123–1130. doi:10.1016/S0043-1648(99)00089-7.

[7] J.C.A. Batista, C. Godoy, V.T.L. Buono, A. Matthews, Characterisation of duplex and non-duplex (Ti, Al)N and Cr-N PVD coatings, Mater. Sci. Eng. A. 336 (2002) 39–51. doi:10.1016/S0921-5093(01)01953-0.

[8] S. Taktak, S. Ulker, I. Gunes, High temperature wear and friction properties of duplex surface treated bearing steels, Surf. Coatings Technol. 202 (2008) 3367–3377. doi:10.1016/j.surfcoat.2007.12.015.