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Effects of AlCrN Coating, Annealing Treated on AlCrN Coating and their Tribological Properties of D2 Steel

Vijayasarathi Prabakaran*

Keywords: D2 Steel, AlCrN Coating, PVD technique, SAE 20W40 lubricating oil, Pin-on-Disc, Surface Modification, Tribological properties, Macroscopic and SEM.

ABSTRACT

Experimentally studied the effect of Annealing treated on AlCrN coating surface modification and AlCrN coating on the wear performance of High-carbon high-chromium AISI D2 steel in wet sliding. The Alcrona (AlCrN) coating was deposited with a thickness of about 4 ± 1μm using a PVD technique on to the polished surface of AISID2 steel. Pin-on-disc testing method with an ASTMG99 standard are carried out. To determine the tribological properties with a three series of load 10N, 20N and 30N for a sliding distance of 4500m at a constant velocity of 1.256 ms-1. The friction co-efficient and wear factor are analyzed primarily. The test results exposed that the Annealing treated on Alcrona AlCrN coating surface modification specimen shows better wear resistance as compared to Alcrona (AlCrN) coating on polished surface specimen. The grooved region, plugging, pits and cavities were examined on the tested specimen surface using macroscopic and scanning electron microscopy (SEM). Hence, the result of this study can be applied to improve the wear resistance in the application of AISID2 steel.

INTRODUCTION

High-carbon High-chromium AISI D2 steel has high hardness and rich chromium alloy carbides are present. It is used as numerous applications of blanking dies, drawing dies, extrusion die, thread rolling die and metal forming die, punches, gauges and shearing blades. The general properties like good toughness, resilience, hardenability, wear resistance, corrosion resistance and temperature resistance. But the main disadvantage of the use is its higher coefficient of friction during metal-to-metal contact. This research work aims to reduce the direct metal contact between the contact surfaces as well as the friction co-efficient and wear factor. Recent literature review have shown that the surface modification method makes it possible to enhance the tribological and mechanical properties of the materials, reported by Li et al. (2014), Cho et al. (2015) and Amanov et al. (2014). Many surface modification method have been submitted to different industries. Fedrizzi et al. (2004), Singh et al. (2015), Lin et al. (2020), Karakaş (2020), Priyan et al. (2014) & Ilaiyavel et al. (2012) have examined, in many technical applications, such as blanking dies, drawing dies, extrusion die, cutting tools, hard disk drives, etc. thin coatings have been widely used to enhance the resistance to wear and improve the performance of mechanical components. Nowadays, most of the industrial practices largely use physical vapor deposited (PVD) techniques. Jindal et al. (1999), Swadźba et al (1996), Polcar et al. (2005), Vijayasarathi et al. (2015-2019) investigated for a long time, physical vapour deposition (PVD) processes were used in the preparation of hard coatings. Cadena et al. (2013), Endrino et al. (2006 & 2007) & Mo et al. (2009) have examined that the AlCrN coatings have been used in the industry for their high wear resistance, low friction and adherence between the tool and working piece. Generally, mineral oil has good characteristics and is cost-effective. Main functions it has for controlling friction, wear and surface damage of machine components such as gears and bearings. Secondary functions have to preclude corrosion and to hunt heat, grime and wear debris, lubricants can also transfer either force or energy as occur in hydraulic systems. Additives are chemically that enhance the properties of oil. Kumar et al. (2021) studied AlCrN coating with oil-lubricating has a low coefficient of friction and wear volume resulting from higher wear resistance. Hao et al. (2012) investigated that the oil retention capacity increases as the porosity of the materials increases. The friction coefficient of porous

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* *Associate Professor, Department of Mechanical Engineering, Veltech Hightech Dr Rangarajan Dr Sakunthala Engineering college, Chennai*

materials is based on porosity and pore size. Pore-impregnated oil plays an important role in enhancing the friction behaviour of porous materials. The advantage of annealing treatment is that the coating is more capable of retaining the lubricant as reported by Hivart et al. (1998).

Novelty of this work

Based on the above review, it is clear that AlCrN PVD coatings improve the abrasive and wear resistance of adhesives, the corrosion resistance and the high resistance to oxidation. To the knowledge of the publication of the work concerning the surface modification of the AlCrN coating is rather limited. In this study the new technique that this Annealing treated on AlCrN coating surface modification of AISID2 steel may be beneficial for improving the sliding behavior, friction co-efficient, oil retaining capability and tribological properties. The effect of the grooved region, plugging, pitting and cavities was observed on the test specimen using SEM scanning and macroscopic electron microscopy.

MATERIALS AND METHODS

In the present study, D2 steel was used as a substrate of elemental composition of (1.5wt%C), (0.41wt%Si), (0.74 wt% Mn), (12.01wt%Cr), (0.01 wt%Ni), (1.01wt%Mo), (0.27wt%V), (0.01wt%Ti), (0.03wt%S), (0.03wt%P). The test samples (Ø8mm and 50 mm length) were prepared and maintained at Ra=0.10μ. The test sample were preserved in 10% sulphuric acid at 70-80°C for 10 minutes and cleaned in 10% HCl at 27°C, then soaked in deionized water.

Coating deposition

Coating preparation were carried out using a PVD technique with argon (Ar) and pure nitrogen atmosphere. Further Current density from -40 to -170 V and 3.5 Pa pressure was used as a process variable, as reported by Jindal et al. (1999), Swadźba et al. (1996), Polcar et al. (2005), Vijayasarathi et al. (2015-2019). Figure 1 shows the cross-sectional view of the AlCrN coating test piece, which is 4 ± 1μm thick. An AlCrN coating was confirmed by EDS analysis in Figure 2. The AlCrN-coated samples were slowly heated from 450°C to 550°C and preserved for 30 minutes. After that, it is cooled in the oven to reach the ambient temperature. From Figure 3, it is possible to observe that the surface treatment procedure. The 3D Surface Roughness of the Uncoated and Coated surface as shown in Figure 4. Development such as the gap formed within the grain boundaries in magnitude of 10 to 15 microns as shown in Figure 5. After annealing the coated specimen are immersed in the oil lubricant for approximately 15 to 20 minutes at ambient temperature. This result justify the gap of the grain boundaries facilitates the retaining the large quantity of oil. The XRD analysis shows the AlCrN coating phase, finely ground and homogenized throughout the surface as shown in Figure 6, reported by Vijayasarathi et al. (2015-2019).

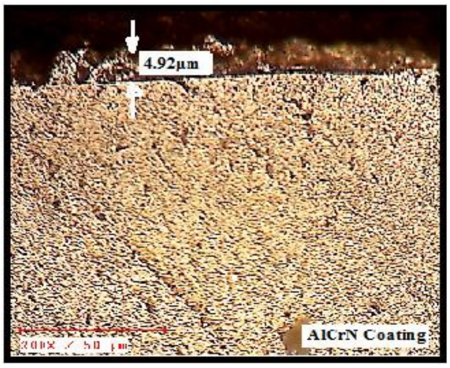


Fig. 1 Microscope image of cross section of coated substrate

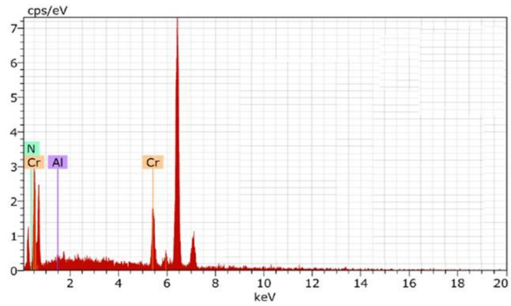


Fig.2. EDS analyses for AlCrN coated surface.

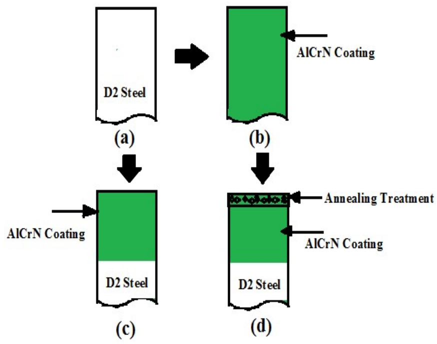
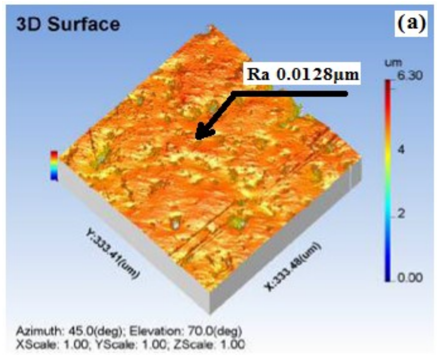


Fig.3. Schematic representation showing the surface treatment procedure: (a) AISI D2 steel specimen (b) & (c) AlCrN (d) Annealing Treatment on AlCrN coating surface.



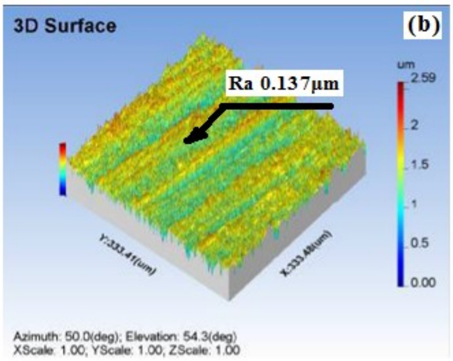


Fig.4 3D Surface Roughness of the Uncoated and Coated surface

GRAIN BOUNDARIES

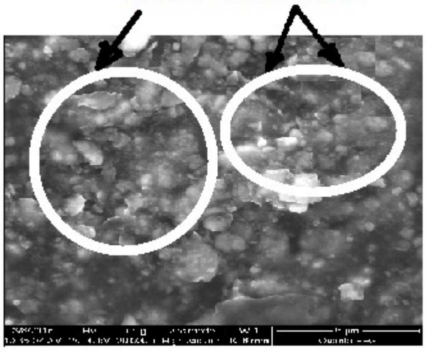


Fig.5. SEM image of the Annealing treated on AlCrN coating surface

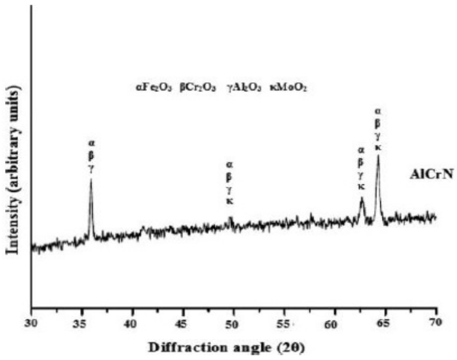


Fig. 6 XRD pattern for AlCrN coating

Tribological test

According to ASTMG99, under oil-lubricated condition the tribometer tests were executed with a three series load of 10, 20 and 30N on a pin-on-disc tribometer with a constant sliding velocity of 1.256m/s at room temperature. Prior to the sliding process, the SAE20W40 oil was used as a lubricating oil, and the coating samples were immersed in the lubricating oil for approximately 15 to 20 minutes. During each test, the coefficient of friction was monitored on a continuous basis. Following the tribometer test, the wear marks on the coated pin were observed by the Talysurf surface profile meter. The amount of wear rate in the coated pin was measured by using this Eq.1 shown below.

$$W = V / d \times P \quad (1)$$

Where 'V is the material removed volume from the coated pin observed by Talysurf Surface profilometer, 'd' is the sliding distance and 'P' is the applied load.

RESULTS AND DISCUSSION

Oil Retaining Capacity

The testing specimen were immersed in lubricating oil for a period of 15 to 20 min at the room temperature. The specimen was takeout from the oil and the oil dripping from the pieces was absorbed using filter papers. Subsequently, the pieces were assessed before and after the oil dip was recorded. By calculating the weight of the samples before and after oil retention, the quantity of oil retained by the samples was determined. Calculating the weight of the samples before and after oil retention determined the amount of oil retained by the samples. The quantity of oil retained by the sample also varies according to the variation in surface roughness values. The test result shows that the quantity of oil reserved by the Annealing treated on AlCrN coating sample was around 0.058, 0.060, 0.0586 grams. Followed by AlCrN coating and uncoated samples was around 0.048, 0.05, 0.046 grams and 0.020, 0.0198, 0.021 grams. Du et al. (2010), Durak (2003), Nakajima (2007) & Hao et al. (2012) also reported that the major role in increasing the friction behaviour of the slide and changes as surface roughness values change. The coefficient of friction of porous materials is dependent upon porosity and pore size.

Hardness

In accordance with ASTM E92-16, the hardness test were carried out using Vickers hardness tester at 0.5Kg load with a dwell time of 10s. Bressan, J. D et al (2008), Bull, S. J et al (2003), Lin, J et al (2008) & Vijayasarathi, P et al (2015,2016, 2017,2018 & 2019) also reported that the hardness of the material is an important aspect to resist the wear resistance. The AlCrN coating exhibited the highest hardness, about 2796HV which is about 3 times higher than that of the uncoated D2 steel (890 HV). Annealing treated on AlCrN coating had a hardness of 2800 HV. The hardness test result is shown in Fig. 7.

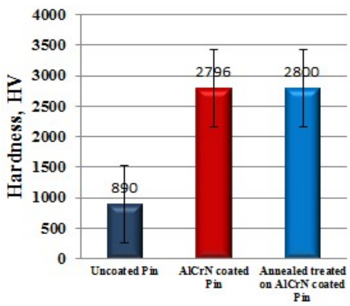


Fig 7. Vickers hardness of PVD-coated AISID2 Steel

Coefficient of friction

The evaluation of coefficient of friction during the pin on disc tribometer test at three series of load 10N, 20N and 30N with oil lubricant is shown in Figure 8.

At 10N load: At the beginning of the test the friction started out approximately 0.4μ for uncoated pin, 0.35μ for AlCrN coated pin and 0.33μ for Annealing treatment on AlCrN coated pin. The reason implies that the uneven surface contact between pin and disc. This result shows that the positive curve slope of friction coefficient against sliding distance. After few second the flat surface comes in contact and streamline of the friction was observed. After a sliding distance of 1930m the uncoated pin gets evaporated oil film followed by the corresponding curve slow gradual increase. For an AlCrN coated pin gets evaporated oil film after a distance of 2650m. But in the state of annealing treatment on AlCrN coated pin gets evaporates oil film after a sliding distance of 4000m.

At 20N load: The coefficient of friction started out nearly 0.28μ for uncoated, 0.26μ for AlCrN coated and 0.26μ for Annealing treatment on AlCrN coated is initially lower co-efficient of friction as compared with previous case and gradually gets negative curve slope of friction co-efficient were observed. After a sliding distance of 1796m the uncoated pin gets evaporated. For an AlCrN coated pin and annealing treatment on AlCrN coated pin gets evaporated after a sliding distance of 2750m and 4200m respectively.

At 30N load: The average coefficient of friction of uncoated pin is about 0.30μ, AlCrN coated pin is about 0.23μ and annealing treatment on AlCrN coated pin is about 0.17μ. This result shows that the lower value of friction as compared with 10N and 20N load. It is proven that the friction coefficient decreases with increasing load which is also observed in Weng et al. (1997) & Chowdhury et al. (2011). But in case of oil lubricant fails, for an uncoated pin after a sliding distance of 2900m, for an AlCrN coated pin after a sliding distance of 3000m and annealing treatment on AlCrN coated pin oil lubricant partially fails after 4400m.

Wear rate

The change in the wear rate of the test pieces quantified after wear tests at three different loads 10N, 20N and 30N with oil lubricant is shown in Figure 9. Liew et al. (2008 &2013), Vijayasarathi et al. (2015-2019) & Wang (2015) also reported that the wear rate increased with increasing normal load. The wear rate was calculated in accordance with Equation 1. The result of the wear test can be shown that the AlCrN coating and annealing treated on AlCrN coated specimens significantly improved the wear resistance. Moreover, it was revealed that the annealing treated on AlCrN coated specimen showed an increase in wear resistance compared to that of the AlCrN coated specimen. This result justifies a higher hardness to increase the wear resistance of the steel substrate, also reported by Bressan et al. (2008).

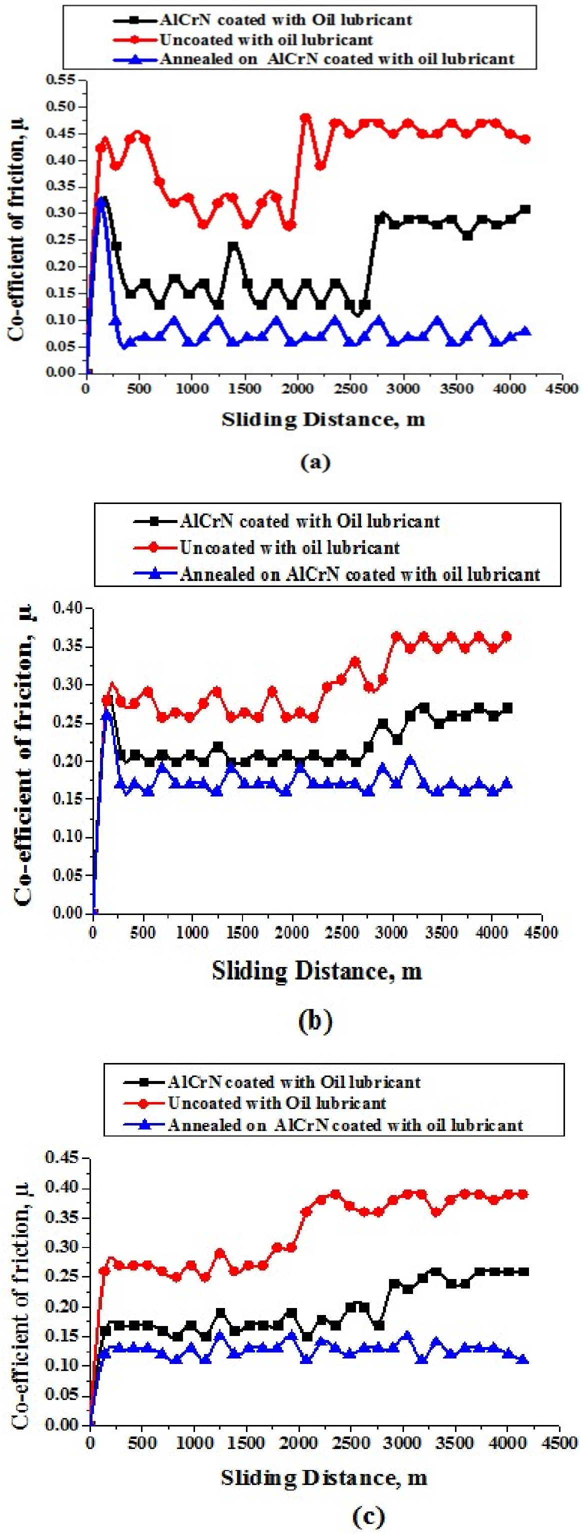


Fig. 8. Friction coefficient of uncoated and coated films with oil lubricant at different applied loads: a) applied load = 10 N, b) applied load = 20 N and c) applied load = 30 N

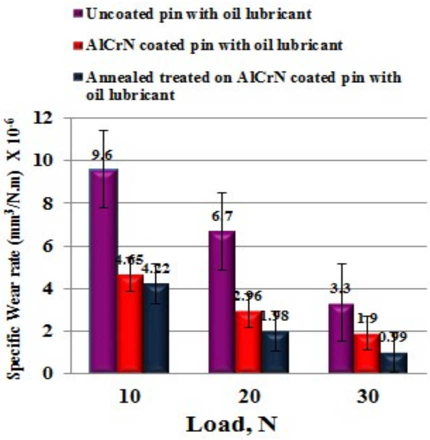


Fig. 9. Specific wear rate Vs load at the velocity of 1.256 m/s.

Worn Out Surface

The Macro image of the worn surface under 30N load at ambient temperature as exposed in Figure 9. The high wear of the adhesive and abrasive was visible on the uncoated pin. After a few meters of operation within the process, it allows the contact surfaces to weld, also reported by ASHBY et al. (1992). This result may be formed as a torn or pitting called galling. As predicted, the wear volume loss exceeded 30 N compared to 10 N. It is seen with the increase in the severity of the wear condition from 10N to 30N of the abrasive wear rate for D2 steel. Moore (1974) & Ueda et al. (2012) also reported that increased volume loss is the result of structural changes due to increased wear depth by coarse particles at a 30N load. The iron oxide film provides a lubrication film with low shear resistance reducing the subsequent frictional contact between the surface and the abrasive particles as reported by Hutchings (1992) & Ilaiyavel et al. (2012). Therefore, wear debris particles and worn-out surface were observed in Macro and SEM images of Figure 10 (a). Also the bending deformation observed on the uncoated pin, but no plastic deformation occurs on the AlCrN coated pin. The high hardness of the AlCrN coating improves the wear resistance of the coated surface. The AlCrN coated pin with oil lubricant possessed a small co-efficient of friction. The presence of pores in the coating may increase the oil retaining capacity, which is also reported in Wang et al. (2015), Yang (1999), Zhang et al. (2003), Bhushan (1996) & Weng et al. (1997). This result the bonding ability between substrate and coating surface is improved. After few meters running in the process, the oil film breaks dry sliding created. It was found that the dense oxide mixture layers of Cr_2O_3 and Al_2O_3 formed on the surface of the AlCrN coated specimen has sustained the abrasion without spalling. This oxide layer improves the wear resistance and reduces the wear loss, which is also reported by Banakh et al. (2003), Endrino et al. (2006-2007)], Kawate et al. (2003), Liew et al. (2008 & 2013), Lin et al. (2008), Reiter et al. (2005). Hence, the result shows, a slight adhesion and abrasive wear of the AlCrN-coated pin as observed from Macro and SEM image in Figure 10 (b). The Annealed treated on AlCrN coated pin exhibits a mild adhesive wear track confirmed by the weight measurement method. The reason implies that the annealing treatment creates the micro cracks which are sheer to the substrate surface. This result the cracks increases the oil reservoir capacity and longer sliding distance which is also absorbed in Du et al. (2010 & 2012) & Mello et al. (2007). Pore-impregnated oil plays a vital role in enhancing the friction behaviour of porous materials. Based on the observation, the Annealing treated with AlCrN coating possessed highly beneficial in oil lubricating conditions.Then, the test result confirms the superior wear resistance performance as an evidence the SEM image Figure 10(c) shows a very little worn out surface and mild adhesive wear.

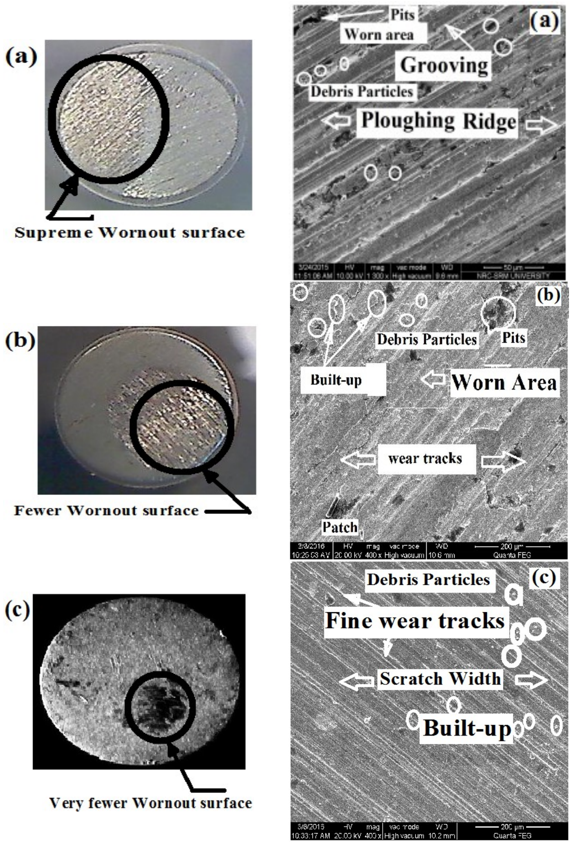


Fig. 10. Macro and SEM images of the worn surface produced at 30N load: (a). Uncoated pin; (b). AlCrN coated pin and (c). Annealing treated on AlCrN coated pin

CONCLUSIONS

In this study, the effects of Annealing treated on AlCrN coating and AlCrN coating on the tribological properties of AISID2 steel were investigated.

- The Annealing treated on AlCrN coating and AlCrN coating had good wear properties and friction compared with uncoated AISI D2 steel.
- Increasing hardness and reducing interacting contact surfaces can improved high resistance to wear, low friction and good adhesion.
- The impact of AlCrN D2 coated steel was observed, enhancing tribological properties.
- The presence of porosity in nature, the AlCrN coating has an ability to retain oil to improve tribological properties.
- Annealing treated on AlCrN coated surface creates micro cracks on the coating surface and increases the ability to retain oil. This result improves wear resistance and longer sliding distance.
- The Macro and SEM image shows deepest wear track on the uncoated AISI D2 and shallow wear track on the AlCrN coated annealing surface.
- The wear loss against the three samples is in the order Annealing on AlCrN > AlCrN > D2 steel.

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NOMENCLATURE

Min – Minimum

m – Meter

Max – Maximum

μm – Micrometer

mg – Milligram

EDAX - Energy-Dispersive X-Ray Analysis

2Θ - Diffraction Angle

ASTM - American Society for Testing and Materials

EDS - Energy Dispersive Spectroscopy

PVD - Physical Vapor Deposition

% - Percentage

AlCrN - Aluminium Chromium Nitride

TiN - Titanium Nitride

XRD - X-Ray Diffraction

λ - X-Ray Wavelength

ANOVA - Analysis of Variance

SNR - Signal to Noise Ratio