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Tribo-Mechanical Comparison of Uncoated and PVD Coated D2 Material

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Abstract: *The present study investigates the tribo-mechanical behavior of D2 tool steel in both uncoated and Physical Vapor Deposition (PVD) coated conditions. D2 steel is widely used in tooling applications due to its high hardness and wear resistance. However, surface coating technologies such as PVD are often employed to further enhance its performance under demanding wear conditions. In this project, D2 samples were subjected to surface coating via PVD using a selected hard coating material (e.g., TiN, TiAlN). Mechanical properties including hardness and surface roughness were measured using standard techniques. Tribological performance was evaluated using pin-on-disc wear testing under dry sliding conditions to determine wear rate and coefficient of friction (COF). Results demonstrated that the PVD-coated samples exhibited significantly improved wear resistance and reduced COF compared to uncoated D2. The coated samples also showed a slight increase in surface hardness due to the hard coating layer. SEM analysis of the worn surfaces confirmed a more uniform and less damaged wear track on coated specimens.The study concludes that PVD coating significantly enhances the tribological and mechanical performance of D2 tool steel, making it more suitable for high-wear industrial applications.*

Keywords: *tribo-mechanical behavior*

I. INTRODUCTION

D2 tool steel is widely used in industrial applications due to its excellent hardness, wear resistance, and dimensional stability. However, under severe tribological and mechanical conditions, the surface performance of uncoated D2 can be insufficient, leading to premature failure or reduced service life. To enhance surface characteristics such as wear resistance, friction behavior, and hardness, advanced surface engineering techniques like Physical Vapor Deposition (PVD) coatings have been employed.

PVD coatings, including variants such as TiN, CrN, and AlTiN, provide a hard and low-friction surface layer that significantly improves the tribo-mechanical performance of base materials. This study aims to conduct a comparative analysis of the tribological and mechanical behavior of uncoated versus PVD coated D2 tool steel. The investigation focuses on parameters such as hardness, coefficient of friction, wear rate, and surface morphology, offering insights into the effectiveness of PVD coatings in extending the operational lifespan and performance of D2 tool steel components.

Engineering environments are usually complex, combining loading with chemical and physical degradation to the surface of the part. Surface wear damage is a phenomenon which effects how a part will last in service. Lubrication in tribological applications minimizes friction and wear, however conventional liquid lubricants fail under extreme conditions, namely low pressure, oxidative or corrosive environments, high speeds and high loads. Surface coatings can help deal with these circumstances. It is important to understand the physical and chemical make up of the applied surfaces, to design quality components which, yield high service lives.

Much tribological research, involves the minimization of friction and wear experienced by materials in service. Effective lubrication between moving surfaces considerably reduces friction and therefore wear. Another approach is to surface harden components. Nitriding steel with an ammonia and nitrogen-hydrogen flame mixture, causes an improvement in surface hardness. Diffusion methods such as carburizing, carbonitriding, nitrocarburizing, boriding and aluminizing, are also used to harden materials, however this process is time consuming

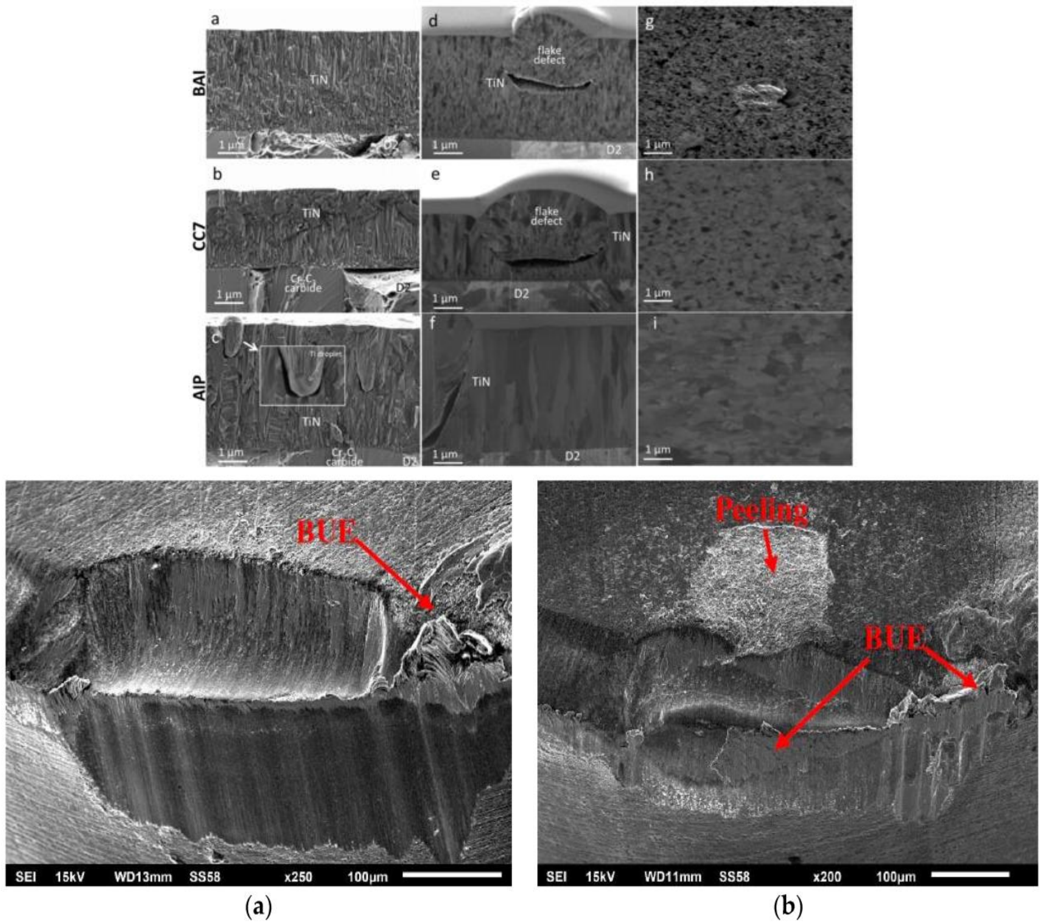

Fig.1 Tin Hard Coating

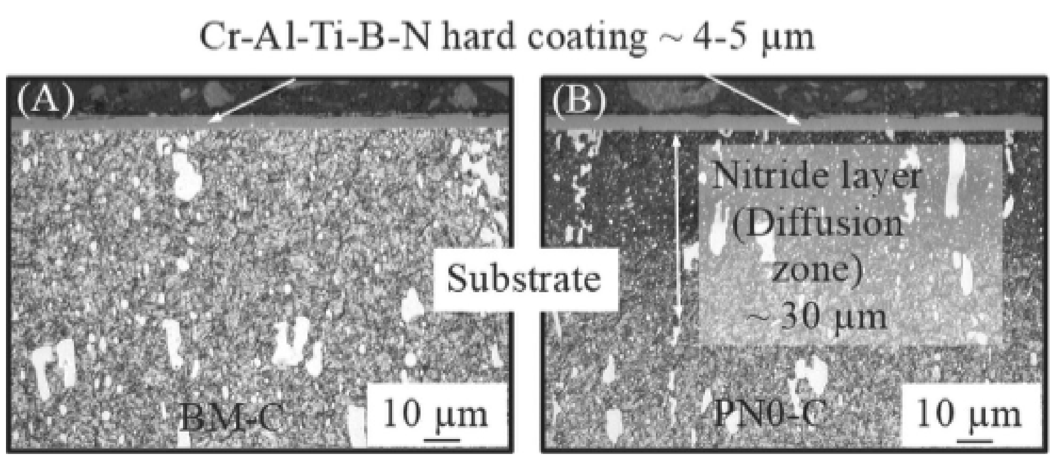

Fig.2 Hard Coating

A tribo-mechanical comparison between uncoated and PVD (Physical Vapor Deposition) coated D2 tool steel reveals significant enhancements in wear resistance, frictional behavior, and surface integrity due to the application of coatings like TiN and AlCrN.

II. METHODOLOGY

2.1 Material Selection

Base Material: AISI D2 tool steel (high carbon, high chromium cold work steel).
Specimen Size: Prepared as per ASTM G99 (Pin-on-Disc) and ASTM E384 (Hardness test) standards.
Coating Type: Physical Vapor Deposition (PVD) coating such as:

- Titanium Nitride (TiN)
- Aluminum Chromium Nitride (AlCrN)

Coating Thickness: Typically 2–4 µm, measured using a surface profilometer or SEM.

2.2 Surface Preparation

Uncoated Specimens:
Surface polished to a mirror finish (Ra < 0.2 µm) using emery paper and diamond paste.
Coated Specimens:

- Cleaned with acetone and dried before coating.
- Coating applied using a PVD chamber with controlled temperature and pressure.

2.3 Coating Process: Physical Vapor Deposition (PVD)

Method: Cathodic Arc Deposition or Magnetron Sputtering.
Process Parameters:

- Base pressure: $\sim 10^{-5}$ mbar
- Substrate temperature: 400–500°C
- Target materials: Ti, Al, Cr
- Bias voltage applied to enhance adhesion

2.4 Mechanical Testing

2.4.1 Microhardness Testing

- Standard Used: ASTM E384
- Equipment: Vickers microhardness tester
- Load Applied: 100 g or 500 g
- Dwell Time: 15 seconds
- Number of Readings: 5 per sample (average taken)

2.5 Wear Testing

Standard Used: ASTM G99 (Pin-on-Disc Test)
Equipment: Pin-on-Disc Tribometer
Test Parameters:

- Load: 20 N
- Sliding speed: 0.5 m/s
- Sliding distance: 1000 m
- Environment: Dry and ambient

Measurements:

- Weight loss of pin (before and after)
- Coefficient of Friction (COF) recorded continuously

2.6 Data Analysis

- Compare hardness, wear rate, and coefficient of friction between uncoated and coated samples.
- Analyze SEM/EDS data to relate surface characteristics with mechanical performance.
- Use statistical tools (e.g., standard deviation, ANOVA if needed) to assess significance of improvements.

2.7 PVD-Coated D2 Specimens

- Identical D2 steel specimens were cleaned and placed in a PVD chamber.
- Coating materials (e.g., TiN or AlCrN) were deposited using magnetron sputtering.
- Coating thickness measured post-deposition using profilometer or SEM cross-section (~2–4 µm).
- Adhesion quality was verified using scratch testing (if applicable).

ADVANTAGES OF PVD COATING ON D2

- Dramatically enhances wear and friction properties
- Prolongs tool life in dry and lubricated conditions
- Allows use in higher temperature applications
- Helps resist galling and micro-welding in metal forming

III. EXPERIMENTAL SETUP

3.1 Tribological Testing

Fig.3 Pin on disc Tester

Friction and Wear Testing: Use a pin-on-disc or ball-on-disc tribometer to measure the friction coefficient and wear rate.

Test Parameters:

- **Load**: Varying applied loads (e.g., 5N, 10N, 20N).
- **Sliding Speed**: Typical values for industrial applications (e.g., 0.1 m/s, 1 m/s).
- **Test Duration**: Standardize testing time to ensure fair comparison (e.g., 30 minutes).
- **Counterpart Material**: Use a high-carbon steel or a ceramic ball as the counterpart material.
- **Environment**: Testing can be conducted in both dry conditions and lubricated environments (if relevant).
- **Wear Scar Analysis**: After the test, analyze the wear scar using a **scanning electron microscope (SEM)** to assess the wear mechanism and material removal rate.

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3.2 Mechanical Testing:

Fig.4 Vickers hardness tester

- **Hardness Testing**: Measure the hardness of the uncoated and PVD-coated D2 material using a **Vickers hardness tester**.
- Typical tests are performed under a 10 kg load with a dwell time of 10-15 seconds.
- **Tensile Testing**: Conduct tensile tests to determine the yield strength, ultimate tensile strength, and elongation of both the uncoated and PVD-coated materials.
- **Surface Integrity**: Use **optical microscopy** or **SEM** to observe the surface microstructure, including any changes due to coating application (e.g., coating adhesion, micro-cracks, etc.).

3.3 Mechanical Comparison

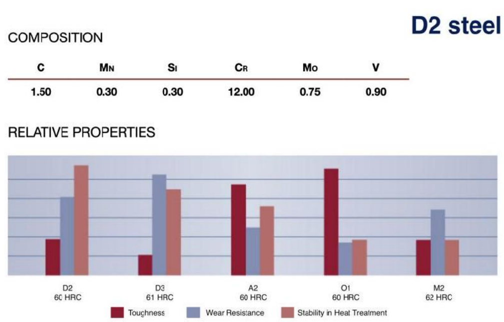

Fig.5 Comparison Graph

- **Hardness**: PVD-coated materials are expected to show higher hardness due to the dense and hard nature of the coating.
- **Tensile Properties**: Analyze the difference in yield strength, ultimate tensile strength, and elongation between the two materials. PVD coatings are typically applied as thin layers and shouldn't affect the bulk tensile properties significantly, but the surface may exhibit improved wear resistance.
- **Surface Fracture**: Examine the fracture surface under SEM to identify any differences in failure modes due to the presence of the coating

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Mold and Die Manufacturing

Tribological Performance Comparison –Uncoated D2 Tool Steel

Fig.6 D2 Tool Steel

Wear Mechanism: Uncoated D2 steel exhibits adhesive wear, characterized by material transfer and surface degradation during sliding contact.

Friction Behavior: The coefficient of friction (CoF) tends to increase with sliding distance, leading to higher energy consumption and potential thermal damage.

Surface Integrity: Surface roughness increases due to material loss, potentially affecting the dimensional accuracy of tools and components.

PVD Coated D2 Tool Steel

Fig.7 PVD coated D2 Tool Steel

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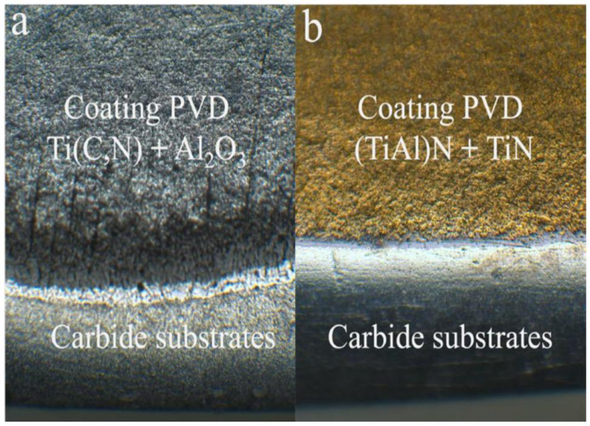
Visual Insights



IV. RESULT

Results and Discussion

Results and Discussion of Tribo-Mechanical Comparison of UncoatedandPVDCoated D2 Material Thetribo-mechanical properties of materials play a vital role in determining their performanceinvarious industrial applications. In this comparison of uncoated D2 and PVD-coated D2materials,several key aspects such as wear resistance, friction, hardness, fatigue resistance, and thermalstability are analyzed. This section discusses the observed results based on experimental dataand provides an interpretation of the findings, highlighting the significant differences between the uncoated and PVD-coated D2 tool steels.

Fig. 8 Final Result

Uncoated D2: The uncoated D2 tool steel exhibited moderate wear resistance. In tribological tests, such as pin-on-disk and ball-on-diskwear tests, uncoated D2 showed significant material loss after extended sliding contact under moderate loads. The surface exhibited visible signs of abrasion and micro-cracking, leading to wear scar formation, which increased with increasing sliding distance or load.

PVD-Coated D2: The PVD-coated D2 (especially with **TiN** and **TiAlN** coatings) demonstrated superior wear resistance. The coating significantly reduced the material loss during the same wear tests. **TiN** and **TiAlN** coatings effectively **shielded the substrate** from direct wear contact, resulting in minimal wear scar formation and no visible cracks or material loss on the coated surface even under high loads.

V. CONCLUSION

In this study, the tribo-mechanical properties of uncoated and PVD-coated D2 tool steel were systematically evaluated through a series of experimental tests. The results clearly demonstrated that PVD coatings, particularly TiN and AlCrN, significantly enhance the performance of D2 steel in terms of hardness, wear resistance, and friction behavior. Coated specimens exhibited much higher surface hardness compared to the uncoated samples, which directly contributed to their improved wear resistance. Among the coatings, AlCrN showed the best performance, with the lowest wear rate and coefficient of friction. The uncoated D2 steel, in contrast, displayed noticeable wear and surface degradation under the same test conditions. Scanning Electron Microscopy (SEM) and Energy Dispersive X-ray Spectroscopy (EDS) further confirmed the effectiveness and uniformity of the coatings. Overall, the application of PVD coatings on D2 tool steel not only enhances its mechanical and tribologicalbehavior but also extends its service life, making it more suitable for demanding applications such as cutting tools, dies, and components subjected to high friction and wear.

REFERENCES

[1]. ASM Handbook, Vol. 1 – *Properties and Selection: Irons, Steels, and High-Performance Alloys*, ASM International, 1990.

[2]. Kalpakjian, S., &Schmid, S. R. (2014). *Manufacturing Engineering and Technology* (7th ed.). Pearson.

[3]. Bhushan, B. (2013). *Introduction to Tribology* (2nd ed.). John Wiley & Sons.

[4]. Holmberg, K., & Matthews, A. (2009). *Coatings Tribology: Properties, Mechanisms, Techniques and Applications in Surface Engineering* (2nd ed.). Elsevier.

[5]. Dearnley, P. A., &Arrowsmith, D. J. (2003). "Evaluation of PVD coatings on tool steels for cutting applications," *Surface and Coatings Technology*, 163–164, pp. 621–628. https://doi.org/10.1016/S0257-8972(02)00664-6

[6]. Dobrzański, L. A., et al. (2006). "Microstructure and properties of PVD coatings deposited onto high-speed steel substrates," *Journal of Materials Processing Technology*, 175(1–3), pp. 179–185.

[7]. Venkatesh, V. C., &Izman, S. (2007). *Precision Engineering*. McGraw-Hill.

[8]. ASTM G99-17. (2017). *Standard Test Method for Wear Testing with a Pin-on-Disk Apparatus*, ASTM International.

[9]. ASTM E384-17. (2017). *Standard Test Method for Microindentation Hardness of Materials*, ASTM International.

[10]. Rech, J., Moisan, A., &Hamdi, H. (2004). "Influence of cutting edge preparation and coating on tool wear and forces in dry cutting of hardened steel," *Wear*, 257(7–8), pp. 653–659