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Characterization of TiAlN PVD Coating on High-Speed Steel Plate

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Abstract
This research investigates the performance enhancement of High-Speed Steel (HSS) using Titanium Aluminum Nitride (TiAlN) coatings applied through Physical Vapor Deposition (PVD) via the Arc method. The coated specimens were tested using CALO test, Rockwell Hardness, Rubber Wheel Abrasion Test, and simulations for stress and thermal behavior. TiAlN significantly improved the thermal, mechanical, and abrasive resistance of HSS, showing its potential in industrial applications where durability and precision are crucial.
Keywords: *High-Speed Steel; TiAlN; Coating; PVD; Hardness; Abrasion.*

1. Introduction
Cutting tools and mechanical components made of High-Speed Steel (HSS) are subjected to wear, friction, and heat during operations. To mitigate performance loss, protective coatings such as Titanium Aluminum Nitride (TiAlN) are employed. TiAlN coatings enhance tool life by improving wear resistance, thermal stability, and reducing oxidation. This study applies the Arc-PVD method to coat HSS and evaluates its performance through detailed experimental methods and simulations. [1]

2. Methodology
M2 grade HSS plates (75 mm × 25 mm × 8 mm) were coated with TiAlN using an Arc-PVD system. The chamber maintained a vacuum environment with a deposition temperature between 450–500°C. The coating material consisted of 60% Titanium and 40% Aluminum, and Nitrogen was supplied as a reactive gas. Pre-cleaned specimens underwent sputter etching before deposition. The coatings were characterized using CALO test for thickness measurement, Rockwell hardness testing for surface resistance, and Rubber Wheel Abrasion test for wear analysis under variable loads and grain sizes. Additionally, finite element simulations were conducted to evaluate temperature distribution in drill bits and stress in spur gears. (Figure 1)

3. Results and Discussion

3.1. Steady-State Thermal Analysis
Simulation analysis demonstrated that the temperature rises in uncoated HSS drill bits reached 964.93°C after drilling 100 holes, while TiAlN-coated bits reached only 908.54°C. The reduced thermal rise confirms better heat resistance and thermal conductivity management. (Figure 2)

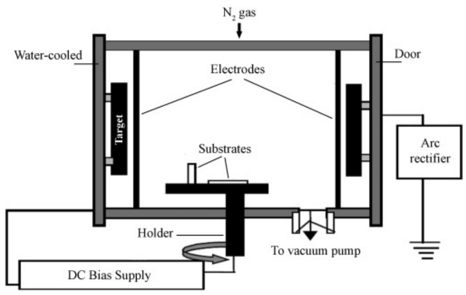

Figure 1 Arc-PVD Coating Setup

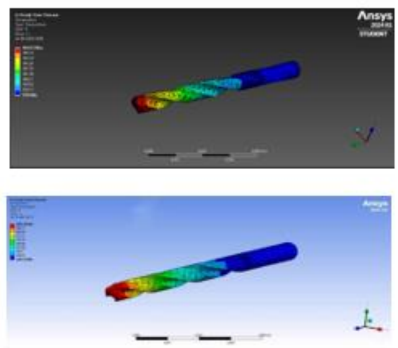

Figure 2 Temperature Distribution in Drill Bits

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3.2. Von Mises Equivalent Stress

Von Mises stress distribution was analyzed in spur gears under a 15000 N torque. The minimum equivalent stress observed was 1352.1 Pa for uncoated, and 831.41 Pa for coated gears, indicating enhanced stress resistance in coated samples. (Figure 3)

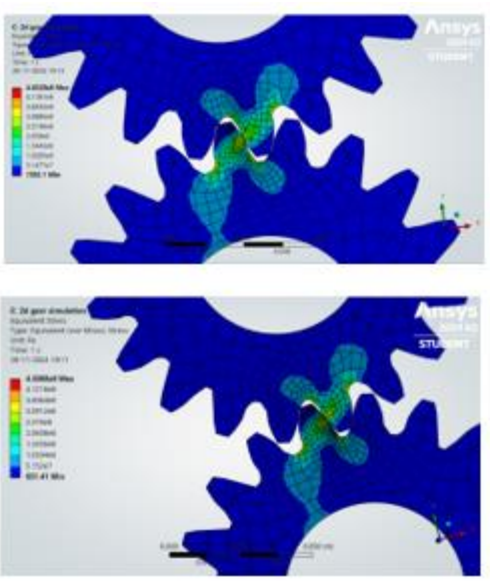

Figure 3 Stress Analysis of Spur Gears

3.3. Coating Thickness Evaluation (CALO Test)

CALO test was performed using a ball diameter of 5 µm. The x and y diameters of the crater were measured and used in the thickness formula, resulting in a coating thickness of 8.1 µm, verifying proper deposition. (Figure 4) [2]

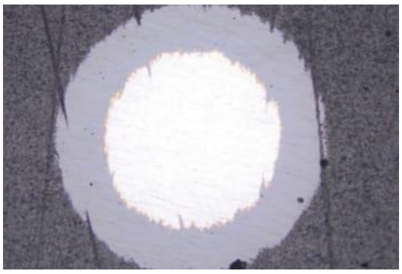

Figure 4 CALO Test Process

3.4. Abrasion Resistance

Weight loss for coated vs uncoated HSS was recorded under varying loads (62, 74, 86 N) and grain sizes (400µ, 600µ, 800µ). TiAlN-coated specimens showed 25–45% lower weight loss. These results confirmed the superior abrasion resistance of the coated samples. (Figure 5) [3]

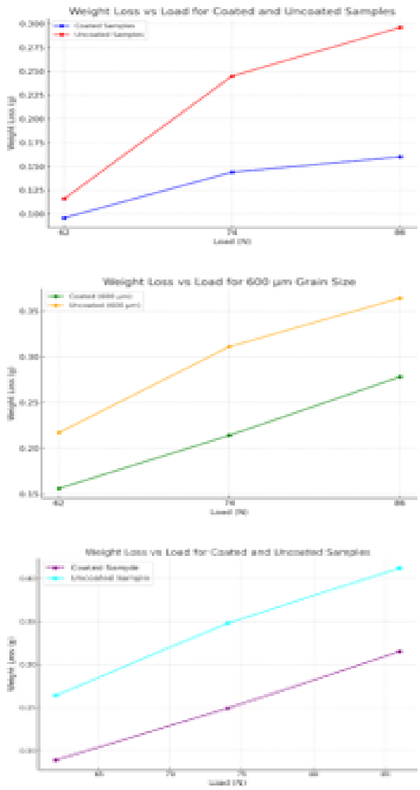

Figure 5 Abrasion Test Graphs

3.5. Rockwell Hardness Test

Rockwell Hardness values were recorded for coated and uncoated specimens using 100, 150, and 187.5 kg loads. Coated samples recorded higher values: 61 HRC (100 kg), 62.1 HRC (150 kg), 56.4 HRC (187.5 kg), compared to 51.8 HRC, 58.5 HRC, and 50.4 HRC for uncoated. (Figure 6) [4]

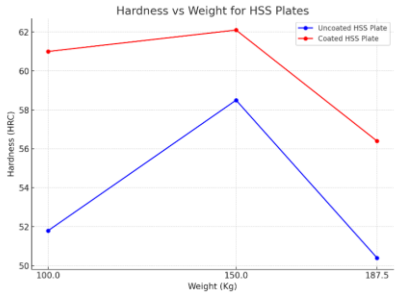

Figure 6 Hardness Comparison

Conclusion

TiAlN coatings significantly improve the properties of HSS by reducing thermal buildup, enhancing wear resistance, and increasing surface hardness. All experimental findings support the adoption of TiAlN-coated HSS in machining and tooling applications where performance and durability are critical. [5]

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