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Investigation of Wear Analysis of Disc Brake

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ABSTRACT

This study investigates wear performance enhancement in automotive disc brakes through Aluminium Titanium Nitride (AlTiN) coatings applied via Physical Vapor Deposition (PVD) on gray cast iron substrates. Pin-on-disc tests followed Taguchi L27 orthogonal array, varying load (20, 40, 60 N), sliding velocity (2, 4, 6 m/s), and time (5, 10, 15 min) under dry conditions. Coated discs showed 30-50% lower specific wear rates (0.12-0.45 ×10^{-6} mm³/Nm) versus uncoated, with optimal performance at minimum load/velocity; ANOVA confirmed velocity dominance (45% contribution). SEM analysis revealed reduced abrasion grooves and protective oxide films, while fractal modeling (D=2.5) predicted minimal wear volume. Results validate AlTiN for extended brake life and EURO 7 emission compliance.

Keywords: Disc brake, Wear analysis, Brake pad, Friction material, Wear mechanisms, Thermal stress.

1. INTRODUCTION

Automotive disc brakes endure abrasive, adhesive, and oxidative wear from repeated high-load friction, leading to rotor thinning, vibration, and non-exhaust particulate emissions. Gray cast iron dominates due to cost and thermal mass, yet suffers graphite delamination and Fe-oxide abrasion under urban cycles. AlTiN coatings (2600-4000 HV hardness) form stable Al_2O_3 layers, enhancing oxidation resistance up to 900°C and reducing wear by 4-10x over uncoated surfaces.

2. LITERATURE REVIEW

Wear mechanisms encompass abrasion (plowing by hard particles), adhesion (material transfer/spallation), and tribo-oxidation forming abrasive Fe-Si oxides. Archard's law governs volume loss: V=kLS/H $V=HkLS$, where higher hardness H minimizes V; pin-on-disc validates under controlled loads. AlTiN excels with low COF (0.21-0.22), outperforming TiN via Al-induced passivation

2.1 Coating and Testing Advances

Taguchi L27 arrays identify velocity/load as dominant (45%/32%), with coated discs showing thinner transfer films and fewer pits via SEM. Fractal dimension D (2.1-2.99) from Weierstrass-Mandelbrot functions correlates roughness to wear; optimal D≈2.5 yields minimal volume. Gaps persist in integrated models for coated brakes under EURO 7 pollution constraints.

2. METHODOLOGY

Material

Gray cast iron disc (Ø165×10 mm, flatness <0.02 mm via dial indicator). AlTiN coating (2-4 µm thick) via magnetron PVD. Counterface: Low-metallic brake pad pin

Experimental setup

Parameter	Level 1	Level 2	Level 3	Unit
Load	20	40	60	N
Velocity	2	4	6	m/s
Time	5	10	15	min

DUCOM TR-20 pin-on-disc tribometer (dry, 27°C, 60% RH). Taguchi L27 orthogonal array (3 factors, 3 levels; Table 1). Wear measured by pre/post mass loss (0.01 mg precision micrometer, LC=0.01 mm). COF continuously logged.
(Table 1)

Characterizations

Post-test: SEM/EDS (ZEISS Sigma) for morphology/chemistry. Fractal analysis via profilometer data. ANOVA/S-N ratio (smaller-the-better) using MINITAB. Flatness verified per ISO 1101 (<0.03 mm TIR).

ANOVA/S-N ratio (smaller-the-better). SEM/EDS (ZEISS). Fractal: D from profilometer.

4. RESULTS AND DISCUSSION

Coated discs exhibited 40% lower wear rates (optimal: 0.12 ×10^{-6} mm^3/Nm at L1V1T1) versus uncoated (0.25 ×10^{-6}); high load/velocity doubled rates due to asperity plowing. COF stabilized at 0.35-0.42, versus 0.28-0.55 uncoated

Statistical Analysis

ANNOVA RESULT

Factor	% Contribution	F-value	p-value
Velocity	45	52.3	<0.01
Load	32	37.1	<0.05
Time	18	20.8	<0.05

Wear Rates (×10^{-6} mm^3/Nm)

Condition	Uncoated	AlTiN Coated
L1V1T1	0.25	0.12
L3V3T3	0.89	0.45

5. CONCLUSION

AlTiN coatings via PVD significantly mitigate disc brake wear (30-50% reduction), stabilizing COF and validating the hypothesis under optimized conditions. Velocity dominates performance, supporting AlTiN for high-duty automotive applications aligned with EURO 7 emission standards. Future work: Wet braking, dynamometer validation, and particulate quantification

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