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Influence of Coatings on the Durability and Friction of Clutch Systems in Motorsport

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Abstract: The article presents a comprehensive analysis of the influence of surface coatings and microtextures on the frictional characteristics and durability of clutch components in professional motorsport applications. The study is based on an interdisciplinary approach that integrates engineering tribology, materials science, and applied mechanics of high-load transmission systems. Particular attention is given to content and comparative analysis of both domestic and international sources describing the behavior of DLC coatings, PTFE-based composites, and iron-based laser claddings under various friction modes, thermal loads, and cyclic stresses. Critical differences between coatings are identified in terms of friction coefficient, wear volume, thermal stability, and adhesion strength to the substrate. Based on empirical data, a typology of coating applicability is proposed for different motorsport disciplines, ranging from circuit racing to rally and drag racing. Summary tables are presented to reflect the operational properties of coatings at temperatures up to 250 °C and under boundary lubrication conditions. The necessity of context-specific coating selection is substantiated, taking into account track configuration, weight constraints, and cooling requirements. Special emphasis is placed on the role of microtextures in heat distribution and contact stress regulation within the clutch. This article will be of interest to design engineers, motorsport specialists, friction system developers, and surface engineering researchers involved in the design of transmission components for extreme operating conditions.

Keywords: clutch, motorsport, coating, friction, wear, DLC, PTFE, laser cladding, microtexture, thermal

stability.

Introduction

Modern motorsport—both on the international stage and within national series—is undergoing a technological shift driven by ever-higher demands on powertrain efficiency, durability and sustainability. Increasing loads on transmission components, intensified thermal and mechanical operating regimes, and the pursuit of weight reduction place the clutch at the forefront of engineering attention as the primary torque-transmission device [1]. Against this backdrop, interest in surface-modification technologies—coatings and texturing—has surged as a means to control tribological behavior and extend component life.

A key challenge, emphasized in both academic and applied literature, is reducing frictional losses while preserving sufficient engagement force and minimizing wear. Iron-based laser claddings, for example, redistribute contact stresses and enhance thermal stability within the clutch assembly [3]. Diamond-like carbon (DLC) coatings and solid-lubricant phases such as PTFE deliver consistent clutch performance at elevated temperatures and under boundary-lubrication conditions [10]. Nanostructured coatings exhibit exceptional resistance to frictional degradation, lowering the risk of functional failure under extreme load [7]. Empirical studies confirm that combining microtexturing with advanced coatings creates a surface “second skin” that adapts to racing conditions and mitigates thermal damage [6].

Practical implementations of these surface-engineering advances appear in GT3 and Formula SAE race cars, where clutches endure maximum wear and fluctuating load cycles. Laser microtexturing and tribologically robust coatings enable teams to achieve repeatable launch torque with minimal slip and clutch-disk overheating.

Integrating functional coatings into clutch design requires a deep understanding of friction mechanisms, wear modes under racing conditions, and the coatings’ ability to withstand thermo-cyclic stresses and contact vibrations. Such research is essential for developing the technological solutions that ensure transmission reliability under the most demanding motorsport scenarios.

The aim of this study is to conduct a comprehensive analysis of how coatings and microtextures affect the tribological characteristics of racing-car clutches, to identify patterns of friction-coefficient changes and component life expectancy depending on surface treatment, and to establish criteria for selecting appropriate coatings for racing applications.

Materials and Methods

The methodological framework of this study sits at the crossroads of engineering tribology, materials science and applied motorsport mechanics, reflecting the complexity of enhancing clutch wear resistance and predictability under extreme loads. A systematic content analysis of experimental and review articles addressing the effects of surface textures and coatings on friction performance and lifespan of clutch assemblies served as the principal research tool.

Sources encompassed both fundamental and applied engineering advances focused on highly stressed interfaces. Of particular note is Tung’s review [5], which summarizes how various surface coatings—including diamond-like carbon (DLC), nitride systems and aluminum thermal-spray layers—affect the frictional behavior of powertrain components. Qiao et al. [3] investigated the combined effects of laser cladding and microtexturing on reducing dry friction and improving wear resistance, outcomes critically important in racing applications. Wu [7] demonstrated the efficacy of DLC coatings under high-frequency mechanical loading and their stability through thermo-cyclic overloads. Di et al. [8] analyzed the spatial organization of microtextures on road surfaces, providing transferable insights into contact-pressure distribution for clutch disc interfaces. Similarly, Ma [10] conducted experimental tests on carbon-reinforced composites mated to steel surfaces, modeling the “disc-pressure-plate” interaction characteristic of racing clutches. He et al. [9] examined how surface-roughness parameters influence the behavior of GCr15 bearing steel, informing understanding of clutch-material thermo-mechanical response under heating.

Additional emphasis was placed on Tung’s work [6], which links surface-architecture design to powertrain reliability, and Wilkinson et al. [2], who evaluated laser-generated biomimetic textures combined with PTFE-based solid lubricants in boundary-lubrication scenarios.

The content analysis proceeded according to the following scheme:

1. Classification of coating types (DLC, nitrides, composites) and texture geometries (point, linear, oriented) based on aggregated literature data;
2. Comparative analysis of tribological metrics (friction coefficient, wear rate, overheating resistance) across operating regimes—dry, boundary and mixed lubrication;
3. Systematization of experimental findings on how surface-treatment methods influence clutch durability and performance consistency under racing conditions.

Visual schematics and tabular summaries from multiple sources provided the basis for constructing an integrated model of frictional interaction that incorporates texture parameters and coating composition. This model reconstructs the primary relationships governing load distribution, heat generation and wear as a function of surface treatment and contact environment.

In sum, the research methodology relies on systematic comparison, critical selection and conceptual integration of published data, enabling identification of robust engineering solutions to improve clutch efficiency in motorsport applications.

Results

A comparative analysis of experimental data from several studies was performed to systematize the frictional behavior of coatings of various types, including DLC, PTFE-based composites with microtextures and iron-based laser claddings. The evaluation covers performance under dry and boundary-lubrication regimes, with emphasis on static and kinetic coefficients of friction. Table 1 summarizes the behavior of each coating under varied test conditions.

Table 1 – Comparison of Friction Coefficients for Different Coatings (Compiled by the author based on sources: [3], [5], [7], [10])

Coating Type	Friction Mode	Friction Coefficient (Static / Kinetic)	Change vs. Uncoated Surface
Uncoated (Steel)	Dry	0.63 / 0.58	–
DLC	Dry	0.18 / 0.15	−70 %
	Boundary lubrication	0.10 / 0.08	−82 %
PTFE + Microtexture	Dry	0.24 / 0.21	−62 %
	Boundary lubrication	0.11 / 0.09	−80 %
Iron-based Laser Cladding	Dry	0.36 / 0.33	−43 %
	Boundary lubrication	0.25 / 0.22	−62 %

PTFE-based microtextured composites deliver performance similar to DLC under boundary lubrication but fall short in fully dry conditions. Iron-based laser claddings yield a moderate friction reduction while offering enhanced durability under peel-off loads [3], [10].

Wear resistance was also compared at temperatures representative of racing-clutch operation. Table 2 presents volumetric wear, microdamage observations and coating-substrate adhesion strength at 150 °C and 250 °C.

Table 2 – Wear Resistance of Coatings at 150 °C and 250 °C (Compiled by the author based on sources: [3], [5], [6], [7])

Coating Type	Temperature (°C)	Volumetric Wear (mm³)	Microdamage	Adhesion Strength
Uncoated	150	8.1	Significant	–
	250	12.6	Critical	–
DLC	150	1.2	None	High
	250	2.5	Slight	Stable
PTFE + Microtexture	150	2.4	Minor	Moderate
	250	4.9	Moderate	Moderate
Iron-Based Laser Cladding	150	3.3	Minor	High
	250	5.7	Moderate	Stable
Nitride Coating (TiN)	150	1.9	None	High
	250	3.4	Slight	High

DLC coatings exhibit the lowest wear rates and strongest adhesion across the temperature range. At 250 °C, only DLC and nitride coatings remain operational without critical damage. PTFE-composites perform well at moderate temperatures but degrade at peak thermal loads, limiting their use in high-heat zones. Iron-based laser claddings demonstrate reliable bond strength and moderate wear, making them suitable where lubrication is unstable and contact pressures are elevated [5], [6].

These findings confirm that coating selection must be guided by the expected thermal regime and contact conditions. DLC and nitride coatings emerge as universal solutions, while PTFE-based composites are best applied where heat dissipation is optimal.

Discussion

The analysis of materials demonstrates that coating type critically determines the development and stabilization of friction under the high-temperature, high-load conditions typical of motorsport clutch systems. Its influence on the time-dependent evolution of the friction coefficient and on clutch thermo-stability across varying operating regimes is particularly significant.

Qiao's work [3] reveals a marked contrast between untreated surfaces and those modified by iron-based laser cladding. Laser-clad coatings exhibit a smoother rise in friction coefficient during initial contact and reduced sensitivity to localized overheating. This behavior is attributed to the formation of a stable oxide layer and the increased microhardness of the clad layer. Diamond-like carbon (DLC) coatings, by contrast, deliver very low friction coefficients (0.08–0.18) and a pronounced self-lubricating effect [7]. Their tribo-chemical structure generates graphite-like fragments at elevated temperatures, which redistribute across the contact zone to form a boundary film that lowers frictional resistance [5].

PTFE-based composites combined with microtexturing function similarly, as Ma [10] demonstrates. Here, directed cooling is the key mechanism: textured micro-channels efficiently extract heat from the contact area, while the low-friction, low-conductivity PTFE acts as a buffer, protecting the substrate from overheating. Compared with DLC, PTFE textures exhibit lower absolute wear resistance (see Table 2) but perform better under frequent thermal cycling. Microtextured coatings maintain reliable heat transfer between mating surfaces, reducing the amplitude of temperature fluctuations—a critical advantage when a racing clutch alternates abruptly between throttle surges and heavy braking.

Selecting an appropriate coating for racing applications cannot be divorced from the specifics of each motorsport discipline, the severity of thermal and impact loads, and the weight and service-life requirements of the components. Table 3 summarizes the key performance criteria that govern coating suitability in professional racing environments.

Table 3 – Summary Assessment of Coating Suitability for Racing Conditions (Compiled by the author based on analysis: [5], [7], [9], [10])

Coating	Thermal Stability	Wear under Impact Load	Coating Weight	Suitability for F1/GT3
DLC	High	Medium	Low	Yes
Iron-Based Laser Cladding	Medium	High	Medium	Yes, with effective cooling
PTFE + Microtexture	Low	Low	Very low	No

DLC-based coatings, despite their higher cost, deliver the optimal combination of thermal resistance and low mass—an essential consideration in F1, where every gram affects vehicle dynamics and handling [7]. By contrast, iron-based laser claddings—valued for their high strength and capacity to absorb impact loads—are well suited to rally and circuit racing, where clutches endure abrupt peak stresses [9]. However, their thermal stability is more limited, and effective deployment demands a robust cooling system and precise operating-mode control, making them less universal for high-speed series with narrow temperature tolerances.

PTFE-composite coatings with microtexturing, while offering minimal weight and very low friction, cannot withstand the thermal and mechanical demands of a racing clutch—particularly at temperatures above 200 °C. Their use may therefore be confined to training or test platforms operating under simplified load profiles [10].

From an economic perspective, the resource intensity of DLC deposition is partly offset by its extended service life and reduced maintenance costs (fewer disc replacements and component repairs) [7]. Conversely, PTFE-based coatings, though inexpensive to apply, rapidly lose functionality, diminishing their cost-effectiveness over a full lifecycle. Laser claddings occupy an intermediate position: they incur significant substrate-preparation and heat-treatment expenses, yet deliver reliable performance under extreme conditions [5].

Accordingly, the most practical approach in motorsport is a context-driven selection of coating technology:

- For F1 and GT3: DLC coatings, for their light weight and thermal stability;
- For rally: iron-based laser claddings, paired with enhanced cooling;
- For drag racing: potential use of hybrid systems featuring PTFE elements during launch phases, albeit with restricted cycle life.

These conclusions emphasize the imperative of integrating tribological, thermal and structural criteria when engineering clutch systems for professional motorsport.

Conclusion

The present study has confirmed the critical importance of surface coatings as a decisive factor influencing the tribological performance and durability of clutch assemblies in motorsport. It has been shown that the choice of coating type can dramatically alter the friction coefficient and determine wear behavior, thermal stability and operational reliability of the clutch under extreme loads.

A comparative analytical review of DLC films, iron-based laser claddings and micro-textured composites demonstrated that no single solution suits every racing discipline. Low-friction coatings such as PTFE fail to deliver the necessary heat resistance and defect-tolerance. In contrast, DLC structures ensure stable friction properties and wear resistance across a wide temperature range, making them the preferred option for circuit racing and Formula classes. Laser-clad coatings offer high impact strength but demand a carefully engineered cooling system and mass-control strategy.

Special emphasis was placed on the influence of surface microtexture on clutch behavior. It was found that the orientation and scale of textured elements can govern heat dissipation and contact-stress distribution, yielding more predictable clutch engagement during transient regimes. This insight paves the way for deliberate surface tuning to match specific track characteristics, coating types and transmission configurations.

Thus, clutch surface modification should be viewed not as an isolated engineering feature but as an integral component of a race car's strategic setup. The findings lay the groundwork for adaptive transmission-component configurations tailored to competition conditions, climate and dynamic requirements. Future research should focus on developing multifunctional coatings that combine low friction, high mechanical strength and controllable thermophysical properties.

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