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# Advancing the Future of Gas Turbines: A Deep Dive into Innovative Wear-Resistant HVOF Coatings for Enhanced Component Performance

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## ABSTRACT

*This paper aims to comprehensively review recent advancements in wear-resistant HVOF coatings for gas turbine components. It explores diverse thermal spray processes, including oxy-fuel methods on steel shafts, assessing their life in compensating for wear. The study also examines challenges related to wear, degradation, and erosion in gas turbine superalloys, particularly in critical components like combustion liners and blades. Notably, real-world performance is highlighted through a case study involving a chromium-carbide-based coating on a gas turbine combustor liner, showcasing increased hardness and minimized wear scars under severe conditions. The overarching objective is to enhance knowledge in gas turbine technology by providing a comprehensive overview of these advancements and their applications in addressing wear-related challenges. This comprehensive review delves into various studies and advancements aimed at mitigating wear and degradation in essential components through the application of specialized coatings.*

***Keywords:*** *HVOF, Wear, Gas turbine components, shaft, blade, Combustion liner*.

## 1.0 Introduction

The realm of industrial engineering and materials science, the quest for enhancing the durability and longevity of critical components, particularly in power transmission, gas turbines, and aviation, has led to extensive research and innovation in the field of wear-resistant coatings. The widespread application of thermal spray processes, particularly oxy-fuel processes, has emerged as a cornerstone for refurbishing worn surfaces, notably steel shafts used in power transmission [1-4].

The effectiveness of these processes is underscored by the meticulous exploration of optimal process parameters through experimental design, with a focus on achieving superior wear resistance. The Pin-on-Disc test, employed as an evaluative metric, provides a quantitative understanding of the performance of different material-coating-parameter combinations [5-7]. In the gas-turbine research field, where extreme temperatures and mechanical stresses pose formidable challenges, superalloys have been indispensable. This review sheds light on the critical components, such as combustion liners, transition pieces, blades, and vanes, which face severe wear during operational cycles. The deployment of hardface coatings, including chromium carbide and Stellite 6, emerges as a pivotal strategy to not only protect these components but also to extend their operational life by reducing friction and wear. Exploring alternative solutions to the environmental concerns associated with hexavalent chromium, the review delves into the development of Cr (Al,Si)N coatings. These coatings, produced through reactive DC magnetron sputtering, exhibit exceptional mechanical properties, offering a promising avenue for applications requiring high resistance to cyclic loads, such as in the mining industry [8-10].

The investigation into plasma-sprayed ceramic coatings introduces another dimension, emphasizing the trade-off between hardness and brittleness. With a meticulous correlation of wear resistance to

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microstructural and micromechanical characteristics, the study provides insights into the potential of these coatings in various wear environments. The application of chromium-carbide coatings through plasma spray techniques in gas turbine combustor liners stands as a testament to the efficacy of hard coatings in minimizing wear damage. The study underscores the work hardening effect of the coating and its impact on wear reduction, offering valuable insights for applications subject to high temperatures and mechanical stresses [11-13].

Furthermore, the review delves into the environmentally conscious shift from hard chromium plating to high-velocity oxy-fuel (HVOF) thermal spraying for repairing gas turbine shafts. Comparative analyses of microstructural properties, wear resistance, and potential applications of various thermal spray coatings underline the viability of these alternatives. As the aviation industry embraces sustainable aviation fuels (SAF), the impact on gas turbine components becomes a critical consideration. The review explores the potential challenges posed by increased water vapor content resulting from alternative fuels, particularly in hot section components, and discusses the implications for component durability. Addressing wear concerns in a gas turbine combustor liner, after 8000 hours of use, a chromium-carbide-based hard coating applied by plasma spray shows a notable improvement in hardness [14-16]. The study highlights the work hardening effect of the coating, showcasing its ability to minimize wear damage under severe temperatures. Transitioning from traditional hard chromium plating to the environmentally friendly HVOF thermal spraying process for gas turbine shaft repair, the study looks into the potentials, wear resistance, and microstructural characteristics of different thermal spray coatings. The study presents thermal spray coatings as feasible alternatives for gas turbine shaft repair and highlights their superiority over electrodeposited hard chromium coatings.

## 2.0 Literature Review

The literature extensively explores advanced coating systems aimed at enhancing the performance and longevity of gas turbine components. Key studies highlight the critical role of specific coatings and their potential as alternatives to traditional methods.Improved performance and dependability of gas turbine components are greatly aided by MCrAlY coatings. An analysis using HVOF has been done in comparison with CoNiCrAlY coatings [12]. Over the past ten years, high-velocity oxy-fuel (HVOF) thermal sprayed cermet coatings have become important in industrial applications that require increased wear resistance and friction. This study was carried out to examine and assess the wear resistance, microstructure, and potential of WC-Co and Cr3C2-NiCr coatings sprayed by HVOF as viable substitutes for hard chromium plating in gas turbine component replacement[21].

Notably, Howmet Thermatech has been granted manufacturing approval to use a TAFA JP-5000 High-Pressure/High-Velocity Oxygen Fuel (HP/HVOF) coating apparatus to coat the next generation of gas turbine engine components with a patented MCrAlY composition. MCrAlY coatings, where M stands for Co or Ni, have long protected hot section components in gas turbines from hot corrosion and oxidation [24]. In the context of clean fuel utility gas turbines, the critical analysis of research and development in thermal barrier coatings for these engines highlights the preference for coating technologies originally developed for airplane applications.

Typically, an MCrAlY bond coat is covered with a zirconia-yttria ceramic that has been plasma-sprayed in these systems. It is mentioned that when molten salts are present, these coatings should not be used. The conversation also explores recent research into the development of corrosion-resistant thermal barrier coatings and attempts to comprehend coating degradation in "dirty" environments[18]. (Ti,Cr)N nanolayer coatings were applied to a variety of substrates, exhibiting enhanced resistance to erosion and corrosion. Increased chromium concentration, packing variables, and coating thickness all affected corrosion performance. Coatings performed better than uncoated surfaces in erosion tests conducted at various angles, with microchipping being the main cause of failure [20].

Hard chrome plating is becoming less used as a means of repairing damaged gas turbine shaft surfaces because of the inherent limitations of its deposits and the potential hazard associated with hexavalent chromium. High velocity oxy-fuel (HVOF) thermal sprayed cermet coatings have become essential in the last ten years for industries that demand superior wear resistance and friction.

There are health and environmental concerns associated with the traditional use of hard chromium plating for gas turbine shaft restoration.

As a greener substitute, high-velocity oxy-fuel (HVOF) thermal spraying is investigated. Promising results are observed when HVOF-sprayed coatings (Tribaloy©-400, Cr3C2-25%NiCr, WC-12%Co) are compared with hard chromium plating. Furthermore, the study looks at HVOF and cold spray methods for oxidation-resistant coating creation in gas turbine blades and discovers that cold spray outperforms HVOF-coated stainless steel in terms of oxidation resistance and wear behavior [15].

Research on the erosion resistance of gas turbine components has shown that the material composition and coating technique have a major influence on component life. Higher surface hardness confirms that WC 84% with cobalt at a 90° nozzle angle is the ideal composition. Conclusions state that the rate of erosion is influenced by the angle of impingement, with a 90° nozzle angle showing the best resistance. In addition, WC 84% with cobalt has the highest hardness and erosion resistance among other coatings based on tungsten carbide [25].

The study compared modern techniques for the deposition of Thermal Barrier Coatings (TBC), such as EBPVD for TBC, low-density YSZ and dense Zircoat, plasma for MCrAlY bond coats, and veiled plasma and HVOF for TBC. A comparison was made of each coating's key features. The evaluation covered indirect materials and services in addition to direct materials, labor, equipment amortization, energy, and gas. Evaluating performance and cost-effectiveness across several TBC deposition techniques was the aim [23].

Tailored laboratory erosion tests are used in the development and selection process of coatings for protecting against erosion in turbine components. These tests incorporate different erodents, temperatures, velocities, and impact angles and are tailored for particular purposes. Coatings for power recovery turbines, aircraft gas turbine compressor sections, and steam turbine blades are a few examples. Super D-Gun coatings made of tungsten carbide and chromium carbide have proven to be more erosion resistant than their D-Gun equivalents without significantly compromising the fatigue capabilities of the blade alloy. Applying laboratory results to hardware designs should be done with caution. Further testing should be considered at the turbine designer's discretion [22].

Turbine blade longevity is increased by erosion-resistant coatings, and contact areas are shielded by fretting-wear-resistant coatings. Hardface coating, particularly Stellite 6 and Chromium Carbide, is essential for prolonging the life of deteriorated gas turbine parts. The material considerations for targeted protection and the particular applications determine its cost-effectiveness [3]. Research gaps in gas turbine coatings include the need for exploration into new coating technologies beyond traditional methods. A comprehensive assessment of the environmental impact, including life cycle analyses, is lacking. There is a demand for long-term corrosion studies and systematic investigations into coating degradation mechanisms.

**Figure 1: Schematic Diagram of HVOF Coating Set up**

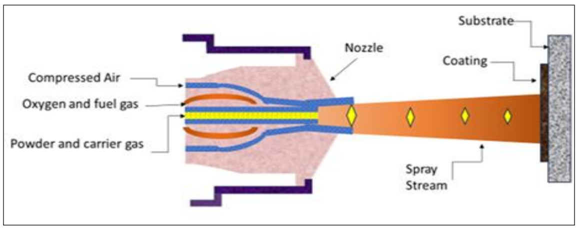



**Figure 2: Wearout Shaft of Gas Turbine[21]**

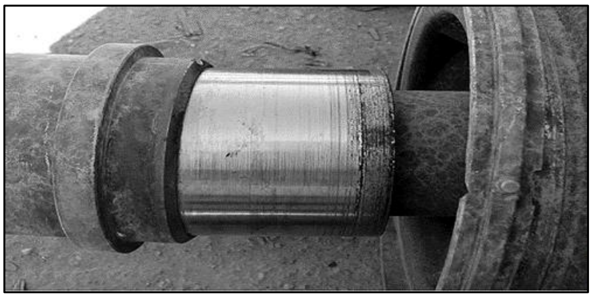
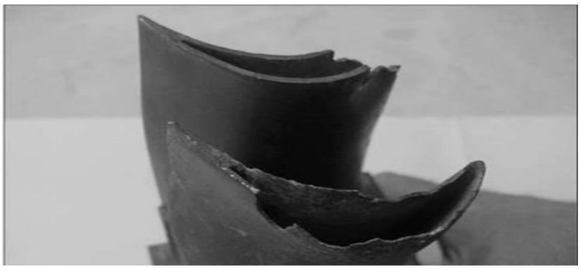


**Figure 3: Wear out Turbine Blade of Gas Turbine[3]**



Comparative analyses across parameters such as cost-effectiveness and adaptability are essential. The absence of standardized testing protocols hampers consistent comparisons. Overall, addressing these gaps is crucial for advancing the understanding and development of sustainable solutions in gas turbine coatings.

## 3.0 Conclusion

In conclusion, the reviewed research collectively addresses critical aspects of wear and erosion in industrial components, presenting innovative solutions ranging from advanced thermal spray processes to environmentally conscious coating alternatives. Despite the advances, there is still a study gap concerning long-term performance and durability under various operating situations. Bridging this gap is crucial for achieving more resilient and sustainable industrial practices in the future.In summary, the literature highlights the significance of MCrAlY coatings in enhancing gas turbine performance.

HVOF-sprayed cermet coatings, particularly Cr3C2-NiCr and WC-Co, show promise as alternatives to hard chromium plating, offering high hardness and wear resistance. Advances in thermal barrier coatings for utility gas turbines prioritize systems developed for clean fuel applications. Nanolayer coatings exhibit improved erosion and corrosion resistance. The diminishing use of hard chrome plating due to environmental concerns has led to investigations into HVOF spraying as a more sustainable option. Comparative studies demonstrate the potential of HVOF-sprayed coatings in gas turbine shaft repair. Overall, the literature underscores the pursuit of environmentally friendly alternatives and innovative coating techniques for improved gas turbine reliability and sustainability.

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