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Effects of Nano Coating on the Mechanical Properties of Turbine Blades: A Review

Adnan A. Ugla, Mushtaq I. Hasan, Zainalabden A. Ibrahim, Dhuha J. Kamil and Hassan J. Khudair

Mechanical Engineering Department, College of Engineering, Advanced Nano-Technology Research Group, University of Thi-Qar, An-Nasiriyah, Iraq– Postcode: 64001

*Corresponding Author Email: zz.zean@yahoo.com

ABSTRACT: A steam turbine's components work under aggressive conditions where operating temperatures range from environmental to near-melting point, contributing to different component degradation. Some parts which lose their dimensional tolerance during use need repair and refurbishment when replacement is avoidable at a high cost. Due to oscillatory vibration action, the compressor blades' dovetail roots are subject to fatigue. The compressor case comes into contact with rotating blades, causing blade damage due to a misalignment shaft, case ovality, or inadequate clearance. Using various contact surfaces undergoing spinning and joint movement takes place during the operation of the turbine. Rotating and stationary parts in the hot sector need a higher working temperature thermal insulation, enhancing the turbine's thermodynamic performance. The application of various coatings that protect the components from failure meets this broad range of functional motor requirements. In terms of not seeking a more in-depth perspective into the field of steam turbine coating, the present review describes the specifics of these coatings at a single stage, application and characterization approaches, and indicative potential directions that are useful to an industrial engineer.

KEYWORDS: nanotechnology; coating; nanocoating; thermal paint; turbine blades.

INTRODUCTION

The most efficient and simplest mechanism that transforms thermal energy into mechanical work is the steam turbine [1]. The expansion of steam increases speed and making the turbine blades powerful [2]. The turbine blades are used to transform the high pressure and temperature linear motion of the entering steam to spin the turbine shaft [3]. In turbine blades, corrosion failure occurs due to chemical reactions, mainly oxidation; the metal wears away or dissolves or is oxidized. It happens when a gas or liquid is chemically attacked an exposed surface, often by a metal. Corrosion is accelerated by high temperatures and acids and salts[4, 5]. Unacceptable failure rates for most blades and discs have contributed to the initiation of several initiatives to explore the problem's root causes [6].

1- The Low Pressure (LP) blade is more vulnerable to loss than the High Pressure (HP) and Moderate Pressure (IP) blades [7].
2- At each engine operating cycle, steam/gas turbine blades are exposed to very high levels of stress and temperature,the predominant blade failures are fatigue-related to vibrations generated in the turbine during transient loads[8, 9].
3- Another big issue during turbines' operation is the dragging of solid particles through gas/steam flow[10, 11].
4- The foreign particles may either be dispersed over the trail and blades of the turbine, causing wear and reducing the turbine's performance, or be fired against the blade surfaces at high velocities, facilitating the creation of corrosion pits in preferential areas that can serve as stress elevators[12-14]

Rani et al. [15] investigated the first stage gas turbine blade of 30MW gas turbine with tip cracks at trailing and leading edges. This blade is made of nickel-based superalloy IN738LC and contains aluminide coating (Pt–Al2). It is found that the blade surface is wholly degraded due to overheating. Corrosion pits are formed on the blade surface; these pits act as a notch to produce stress concentrations. Cracks are initiated due to fatigue, which further propagates[16]. From these investigations, it is concluded that the turbine blade's failure takes place due to the combined effect of surface degradation caused by overheating, oxidation, hot corrosion, and degradation of coating heavily oxidized.

The coating of blades effectively protects the components against a range of causes, such as abrasion, erosion, wear, wear, oxidation, and corrosion [17]–[19]. Taking into account the environment in which the component has its intended purpose [20]. This paper presents a comprehensive overview of the steam/gas turbine blades' nanocoatings and its effect on the mechanical properties, the nanomaterials characterization, processes employed in various coatings methods, and various coatings' failure.

CORROSION

High-temperature components of a steam turbine are exposed to a wide range of thermal and mechanical loads in addition to an oxidizing and corrosive environment[21][22]. as shown in Figure (1). This situation leads to a fall in oxidation and corrosion resistance of the material. Therefore, appropriate coatings are applied to protect the components' surface from oxidation and corrosion[24].

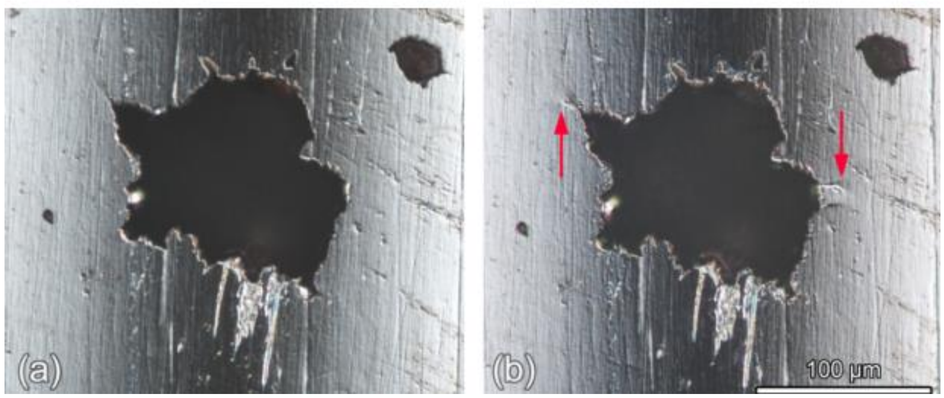

Figure 1. Corrosion pit on the surface[23]

Turbine blade steel (PH13-8)[25] and the (FV3566), which are considered effective turbine blades, were investigated in [26]. The findings show that the crack growth rate for higher strength (PH13-8) steel is approximately higher than that of FV566 steel. The results indicate that the rate of crack growth for the higher strength (PH13-8) steel was about an order of magnitude greater than that for the FV566 steel. Alumina layer deposited on stainless steel samples was investigated[27]–[31]. Mohammed Hussein J. Al –Atia [32] A four-solutions dipping procedure with varying amounts of alumina is used by aluminum isopropoxide dissolving in water. The results show that the possibility of evaluating good protective properties that easily compare the different kinds of thin coatings deposited on the surfaces of the stainless steel by the sol-gel way[33].

In the work of Waheed and Abdalkadir [34], static electrochemical corrosion activity of Fao water for nano (Al2O3) and nano (SiC) was compared. The findings showed that nano (Al2O3) reinforced Al acted at lower corrosion rates relative to nano (SiC) reinforced Al. Jomah [35] utilized thick Al2O3 coatings deposited with Electro Photic Deposition (EPD) to enhance aluminum substrates' corrosion resistance. The results showed that the corrosive resistance of sintering at 400 ° C at 2 hours had minimized the corrosion relative to coverings without sintering for coatings.[36, 37]. Ni–Al2O3 based composite coatings using the High-Velocity Flame Spray (HVFS) system, as shown in Fig.2, were studied in several research types [38, 39]. Grewal et al. [41] studied alumina material's effect using HVFS on the microstructure and various mechanical properties viz. microhardness, fracture toughness, density, residual stress, and scratch resistance were tested. They find that the coatings' alumina content strongly influences microstructural property such as splat size, porosity, un-melted flakes, and surface roughness.

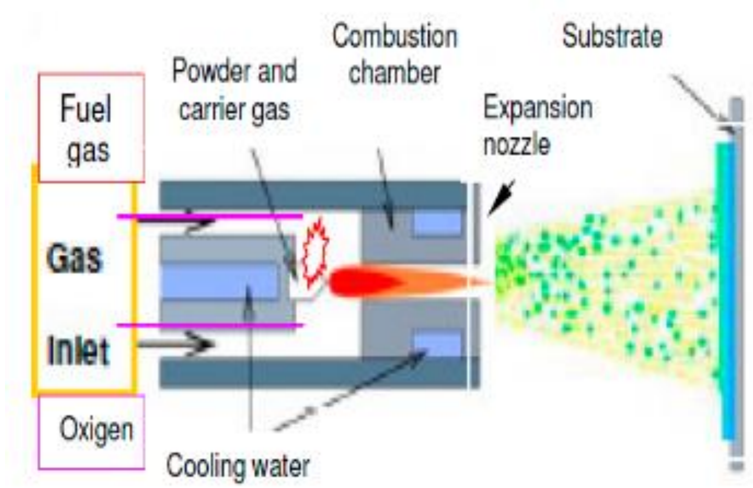

Figure 2. HVFS process schematic representation[40]

Bedaiwi & Abd [42] clarified that to prevent corrosion, nanomaterial coating, Al2O3 and TiO2 are used. It was observed that the corrosion potential of the specimens covered with (Al2O3-13% wt TiO2) has higher corrosion protection than a pure nanoparticle (Al2O3) shell.

FATIGUE

Several mechanisms can cause the blade to fail in turbine operating conditions with high rotational speed at high temperatures. Generally, one of the most critical blade failures due to fatigue, including both high and low cycle fatigue (LCF) [43]–[46].

Kim et al. [47] ceramic coatings such as TiN, TiCN, and TiAlN on fatigue behavior on rotor steel, Cr – Mo – V steel have been studied. The ceramic coating material has been concluded to improve the strength of fatigue. Yang et al. [48] finite element model was developed to analyze the failure behavior for a turbine blade with thermal barrier coatings under cyclic thermal loading. The results indicate that the damage occurred in the chamfer and rabbet of the turbine with a thermal barrier-coated and that its thermal fatigue life decreases with the increase of thermal stress generated by high operating temperatures. Swami et al. [49] produced hard erosion-resistant nanocoatings and evaluation tests. They determined that the coatings' presence does not have any negative implications but positively impacts the high cycle fatigue resistance at zero and high average stresses.

The low cycle fatigue behavior of high-performance Cr-Mo-V hot-working steel was investigated [50]. Glodeža et al. (2017) [51] used fatigue tests for uniform, duplex coating (plasma nitrided and hard PVD coating) test specimens. The result demonstrated that the PVD surface coating has a beneficial effect on material fatigue activity in high cycle fatigue conditions at stress ranges in the elastic domain, providing a longer life of fatigue in contrast with the uncoated specimens. The low cycle fatigue parameters for the uncoated and duplex surface of treated Cr-Mo-V steel were obtained from the experimental.

EROSION

Erosion is a progressive loss of material from a solid surface through mechanical interaction with fluid or solid particles. That is due to the impact of solid particles or water droplets [20, 52]. Fig .3 shows the erosion of the leading edge of the steam turbine blade.

Figure 3. Erosion of the leading edge of steam turbine blade

The premature failure of steam turbine rotor blades manufactured in forged 12% Cr– NiMoV martensitic stainless steel was investigated [53-55]. Azevedo & Sinatora [56] indicates that the blades' loss was promoted by corrosion of foreign particles, which attacked the lower trailing blade edge's low-pressure side. Tu et al.[57] showed that the loss of martensitic blades from the last stage of a steam turbine was examined. The blades cracked in the lead, which also had corrosion marks, and the analysis showed that the fracture was propagated with fatigue.

Chen et al. [58] coated turbine blades to protect against solid particle erosion. The enhancement in corrosion resistance was found to increase the coating's thickness and increase the coating's internal microstructure and chemical composition. Erosion-resistant coatings avoid premature loss of material by compressor blades [56]. Borawski et al. [60] investigated the magnetron-sputtered effect of interlayer content on titanium nitride (TiN) particle erosion efficiency. The multi-layered TiN / Nb multi-layer coatings are the best stable under specific environments. However, the TiN / Ti coatings exhibited maximum longevity against the alumina. This disparity was slight and can be due to the coatings' relative overall thickness.

Chawla et al. [61] examined the degradation and hot corrosion issues in Indian coal-fired power plants. Construction materials of high strength and improved resistance to hostile service atmospheres need to be used to build new coal-fired power generation systems with high thermal efficiency. These tasks can be done with successful coatings. The High-Velocity Oxigen Flame(HVOF) was tested in many experiments using various content types [62-64]. Coatings for abrasion and silt erosion features have been investigated. HVOF coated steel was even more potent than 12 Cr and 13 Cr– 4 Ni plasma-nitrided steels. 12 Cr steel plasma nitride performed better than 13Cr–4Ni steel plasma nitride. This is because of its greater microhardness and its capacity to absorb more nitrogen under identical laboratory plasma nitriding conditions. Mann et al.[65] Studied high power diode laser (HPDL) surface treatment to overcome low-pressure steam turbine (LPST) droplet erosion of moving blades used in high-rating traditional, HPDL surface treatment greatly increased the droplet erosion resistance. The effect is improved stiffness and forming of the fine-grained martensitic phase due to fast laser treatment heating and refreshing speeds.

Twin-wire sprayed arc (TWAS) as shown in fig.4 was investigated in several research types [66-68]. Pant et al. [69] used Twin-wire sprayed arc (TWAS), and plasma nitrocarburized ions were used in the HPDL low-pressure steam turbine (LPST) to overcome droplet erosion. The TWAS X10CrNiMoV1222 nitrocarburized steel and plasma ion surface treating increases the water droplet resistance manifold. Resistance to liquid droplet erosion of two single-layer Ti – Si – C – N. [70]–[72].

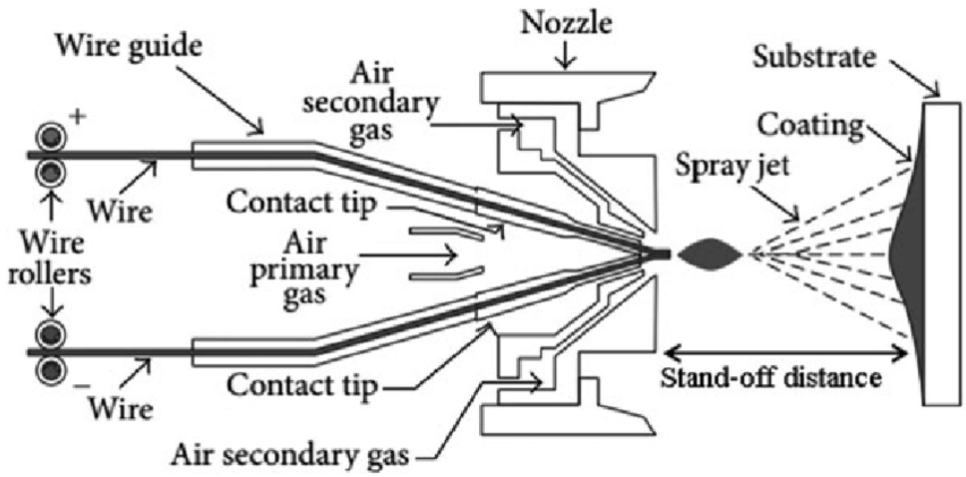

Figure 4. Schematic twin wire arc spraying process [73]

The use of state of the art Plasma Enhanced Magnetron Sputtering (PEMS) technique nanocoatings, as shown in Fig.5 was investigated in ref [74], [75]. Qin et al. [76] indicated that the coatings demonstrated excellent resistance to cavitation erosion in both media compared to the uncoated substrate.

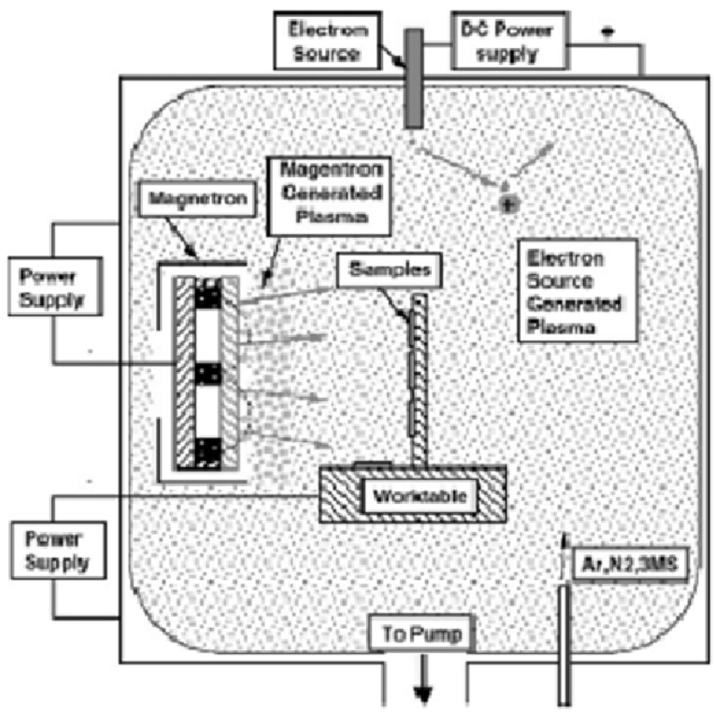

Figure 5. Schematic of enhanced plasma magnetron sputtering (PEMS)[77]

In the work of Swminathan et al. [78], single-layered dense carbonitride PEMS has received approximately 30μm of TiSiCN coatings. The highest low-angle erosion resistance was found by TiSiCN-almost 25 times higher than the Ti-6Al-4V and about 5-10 times higher than all the other nitrides. The methodology of PEMS coating varies considerably from traditional techniques such as Air Plasma Spray (APS)[79], [80], low-pressure plasma spray (LPPS), diffusion coatings, chemical or physical vapour deposition (CVD or PVD) used on blades and vanes. The influence of coating thickness, test temperature, coating hardness, and defects on boride coatings' erosion resistance was studied in [81-84].

CrN ion coatings and thermal spraying coatings have been experimentally tested by Wang et al. [85]. The results indicated that the erosion rates could be efficiently minimized by increasing the coating's hardness and thickness with the absence of coating cracks during the coating process. Boride and ion playing CrN coatings are more desirable to protect steam turbine blades from solid particle erosion owing to better erosion tolerance relative to thermal spraying coatings.[86].

From the other side, six sintered WC-Co hard metals were tested and subjected to a high-speed stream of water droplets; for comparison [87]. The HVOF sprayed the WC-Co coating alongside a titanium alloy. Both sintered materials displayed an incubation time where no harm to a certain exposure level was detected.

Commercial application of coatings was achieved by thermal spraying, arc plasma spraying, and high-velocity oxy-fuel (HVOF) methods [88]. For surface treatments at laboratory stages, boroning, laser surface hardening and cladding, chemical vapor deposition, physical vapor deposition, and plasma nitriding have proved to be effective on the individual materials.

A correlation between the set of strength properties of the coating and its resistance to erosion wear is established by Varavka et al. [89] through this correlation, and inference is drawn on the probability of predicting the behavior of coatings on their preliminary determined strengths under the conditions of droplet impingement erosion.

A pneumatic accelerated erosion method to simulate the actual erosion environment in power units[90]. Cai et al. [91] showed that boride coatings with a more compact composition and higher hardness have more significant antierosion potential under high temperatures' solid particulate erosion. Duplex phase boride coatings (FeB and Fe2B) have a lower potential for antierosion damage than single Fe2B boride coatings.

High Power Impulse Magnetron Sputtering (HIPIMS) deposition technology has been studied in several types of research[92]–[94], Hovsepian et al. [95] used HIPIMS to improve productivity to deposit ceramic-based CrN / NbN coating. Compared to other state-of-the-art PVD technologies, low cycle fatigue and Creep tests demonstrate that HIPIMS is not detrimental to the substrate material's mechanical properties. Water droplet erosion studies show that no weight loss is observable after 2.4x106 impacts.

CONCLUSION

This overview presented various steam turbine coatings, application and characterization methods, degradation mechanisms, and possible future directions. Buildings of several components that have lost their dimensions during service through the coating route are essential for the engine's economic use. As listed in the reviews, the nanocoating in various application types effectively protects the blades from corrosion and significantly reduces the corrosive rate. Meanwhile, the coatings' presence does not have any negative implications but positively impacts the high cycle fatigue resistance at zero and high average stresses. Also, the coating can reduce fatigue in high-cycle fatigue conditions at stress ranges in the elastic domain. Erosion-resistant coatings protect the compressor blade from sand particles and fly ash, thereby improving their performance and life.

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