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Original article

Corrosion reduction in steam turbine blades using nano-composite coating

Sabaa Sattar [a,b], Yaser Alaiwi [a], Nabaa Sattar Radhi [c], Zainab Al-Khafaji [d,e], Osamah Al-Hashimi [f], Hassan Alzahrani [g], Zaher Mundher Yaseen [h,i,*]

[a] Department of Mechanical Engineering, Altinbas University, Istanbul 34217, Turkey
[b] Al-Turath University College, Baghdad, Iraq
[c] Metallurgical Engineering Department, College of Materials Engineering, University of Babylon, Iraq
[d] Department of Civil Engineering, Universiti Kebangsaan Malaysia, 43600 Bangi, Selangor, Malaysia
[e] Building and Construction Techniques Engineering Department, Al-Mustaqbal University, 51001 Hillah, Babil, Iraq
[f] Department of Civil Engineering, LiverpoolJohn Moores University, Liverpool L3 3AF, UK
[g] Department of Geology & Geophysics, College of Science, King Saud University, P.O. Box 2455, Riyadh 11451, Saudi Arabia
[h] Civil and Environmental Engineering Department, King Fahd University of Petroleum & Minerals, Dhahran 31261, Saudi Arabia
[i] Interdisciplinary Research Centre for Membranes and Water Security, King Fahd University of Petroleum & Minerals, Dhahran 31261, Saudi Arabia

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ABSTRACT

The current study aims to reduce the hot corrosion issues in steam turbines for Al-Mussaib thermal power stations. To gain the aim of the study, many experimental tests were conducted by taking a sample from an existing broken steam turbine blade to identify the alloy composition and preparing samples with exact composition by powder metallurgy method, then using the electro-deposition method to coat the prepared samples by three different coating composite materials consists of TiO_2 in different ratios (5, 10 and 15) g/l and 5 g/l SiO_2 added to Watt's solution. To verify the efficiency of coating, several tests were conducted (surface roughness, hardness, wear, and oxidation test). The obtained results indicated that increasing the Ni-5%SiO_2-TiO_2 (5, 10 and 15) g/l caused an increase in the coating thickness, which is compatible with increasing the surface roughness. Also, the sample hardness increased after coating, which returned to increasing TiO_2 amount (5, 10 and 15) g/l. However, wear resistance for the samples after coating by selected coating composite and 10 g/l TiO_2 amount records the highest reduction in the wear of the sample.

1. Introduction

Corrosion fatigue and stress corrosion cracking (SCC) are the two major issues with turbine parts (Zhao et al., 2021). Large amounts of corrosive contaminants in the steam that builds up in a layer on the surface of the parts throughout operational or resting periods in the wet areas of turbines are associated with these problems, which grow primarily from early corrosion pits (Dawood et al., 2020; Jonas, 1985; Radhi & Al-Khafaji, 2018). Due to the higher likelihood of steam condensation, low-pressure (LP) steam turbine bucket problems are more frequent (70%) than those of intermediate-pressure (IP) and high-pressure (HP) turbines (Mukhopadhyay et al., 1998). The HP section receives steam from the main steam lines that have been overheated. Cold reheat piping transports the steam to the reheater after passing thru HP turbine. It then needs to return to the incorporated IP and HP cylinder in the steamy reheat piping to transfer thru the IP exhaust hood. Finally, the crossover piping transports the steam to the LP turbine before exiting to the condenser through the LP exhaust. Every steam turbine contains several extraction points where steam is utilized to heat feedwater heaters (Strušnik, 2022; Vedran et al., 2022). The steam passes the saturation line throughout its expansion via the LP turbine. Corrosion degradation has typically been discovered when condensation first starts. If NaCl is introduced to the system, the salt zone is predicted NaCl amount might reach up to 28 %, which would be sufficient to corrode a steam turbine quickly (Jonas & Machemer, 2008). Because of this, the LP portion of the steam turbine suffers the highest corrosion.

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* Corresponding author.
E-mail address: z.yaseen@kfupm.edu.sa (Z.M. Yaseen).

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Following the scientific revolution propelled by advancements in nanotechnology, the utilization of nanocomposites and hybrid materials has become integral to contemporary scientific and technological research due to their diverse range of applications (Radhi et al., 2022). These materials possess exceptional electrical and mechanical properties, exhibit optical interaction, and demonstrate high thermal conductivity with remarkable efficiency (Abed et al., 2022). The selection of an optimal method for preparing nanocomposites is a critical aspect of the field of research about these intricate materials. "Co-Deposition Techniques" refers to a method that involves using two, three, or more deposition sources. Hence, these diverse or identical sources interact synergistically and adhere to the designated samples, resulting in alloys and hybrids that exhibit exceptional properties (Jasim et al., 2023). The various types of co-deposition include electrolytic co-deposition, co-sputtering, co-evaporation, and spray co-deposition.

The electro-deposition method offers several advantages over alternative coating techniques, including hot isostatic pressing, thermal spraying, and high-velocity oxygen fuel (HVOF) (Zhang & Witman, 2018). These advantages include the ability to continuously process materials, handle complex geometries, operate under normal working pressures, rapid deposition rates, homogeneous distribution of coatings, low maintenance requirements, and decreased generation of waste (Lampke et al., 2006; Szczygieł & Kołodziej, 2005). Electro-codeposition is a highly efficient technique for fabricating Metal Matrix Composite (MMC) coatings (Camargo et al., 2016; Lelevic & Walsh, 2019). This process involves the simultaneous deposition of non-metallic and metallic particles onto pure metals or alloys. The primary objective of electro-codeposition is to enhance the resulting coatings' tribological features and resistant to corrosion (Ger, 2004). In the present context, ongoing research focuses on the co-deposition of ceramic particles, including WC, Al_2O_3, TiO_2, Cr_2O_3, and SiC, in conjunction with nickel plating (Aal et al., 2007; Hu & Chan, 2006). The tribological properties primarily rely on the reinforced particles' quantity, dimensions, and arrangement (Gnjidić et al., 2001; Thiemig et al., 2007). The electroplating parameters, including stirring speed, temperature, pH, current density, and bath composition, have been observed to impact the surface morphology (Kılıç et al., 2013).

(Chen et al., 2010) used conventional electroplating Ni solution mixed with a small quantity of transparent TiO_2 sol to create nanocrystalline Ni-TiO_2 composite coatings. These coatings have such a slick exterior. The usual pyramidal form of the Ni nodules was replaced with a spherical shape. Additionally, the Ni particle size dramatically decreased to 50 nm. The coating matrix included well-scattered amorphous anatase TiO_2 nanoparticles (approximately 10 nm). The innovative composite coating with 3.26 wt% TiO_2 greatly enhanced the microhardness from 320 HV100, the conventional Ni coating, to 430 HV100. As a result, the composite coating's resistance to wear was increased by around 50%.

(Gül et al., 2012) examined the impact of particle amount on the Ni-SiC composite coatings structure made by electro-deposition. They found that Ni-SiC (MMCs) composite coatings enhanced with submicron particles on steel surfaces had good resistance to wear and high hardness, so they were utilized in applications where no wear was preferred, like tools and dies. The solutions raised the SiC particle in the electrolyte, which increased the co-deposited coatings' particle amount. The amount of coating particles decreased up to a max of 20 g/L as the SiC particle amount increased; however, this caused the metal matrix (in this case, Ni) to have its lattice distort; coating resistance to wear improved with SiC particle amount up to 20 g/L in the electrolyte; and nanocomposite Ni-SiC coatings that co-deposited increased friction coefficients and resistance to wear in comparison to films of Ni, which is related to the mixture of submicron-sized (SiC) particles in the deposited layer, strengthening the dispersion and refined grains to raise the composite coating hardness (Abed Janabi et al., 2021).

Prepared Zn-nano-TiO_2 composite coatings were coated on the mild steel substrate by (Mokabber et al., 2013). Electroplating created coatings from a sulphate solution containing nanoscale TiO_2 particles. The coatings' corrosion behaviour was investigated in 3–5 wt% NaCl solutions, and the microhardness was determined using the Vickers microhardness test. The variables of current density, particle content in the solution, and temp are best when compared to the composite coatings' TiO_2 content. The bath was determined to have an optimal current density, particle concentration, and temp of 3 A/dm^2, 5 g/L, and 40 °C. Due to the increase in the number of TiO_2 particles in composite coatings enhances their hardness while having no negative impact on their ability to resist corrosion.

(Gadhari & Sahoo, 2016) explored the addition of titania particles with the micro-hardness, resistance to corrosion and wear, and friction of electroless Ni-P-TiO_2 composite coatings coated on mild steel substrates at various annealing temps. The empirical findings demonstrated that when the particle concentration in the electroless solution rises, more TiO_2 particles are integrated into the coatings. Hardness, resistance to wear, and resistance to coating corrosion all greatly increase in the presence of TiO_2 particles. X-ray diffraction (XRD), energy dispersive X-ray analysis (EDXA), and Scan electron microscopy (SEM) analysis are used to study microstructure changes and composite coating composition.

(Antar et al., 2021) developed Ni-B-TiO_2 composite coatings by including TiO_2 sol in the bath solution. Several characterization tests, such as microhardness testing, progressive load scratch testing, reciprocating sliding testing, and multi-pass scratch testing, were conducted to obtain systematic research. The findings indicate that the microstructure of the Ni-B matrix was effectively altered by the TiO_2 structure (crystal or amorphous). Additionally, the Ni-B deposit's excellent scratch response and improved resistance to wear were offered because of its compact structure.

Al-Mussaib thermal power station is among Iraq's electricity system's most significant power-producing facilities because of its size and closeness to the capital area. As a result, it has a substantial influence on the Iraqi economy. Most reports released from AL-Musayyib thermal power station stated that the main issue that caused the stop or rest of the steam turbine operation was the breaking or cracking of the blades. Therefore, the action that is usually taken to reduce the issues of blades is applying metal coating before the operation to increase the service life of the blades along with decreasing the hot corrosion failure. The current project aims to increase the resistant to hot corrosion of steam turbine blades for AL-Musayyib thermal power stations by applying nanocomposite coating (5 g/l SiO_2 and (5, 10 and 15) g/l TiO_2). Therefore, the novelty of the current research focuses on preparing samples with a similar composition to existing steam turbines experimentally by powder metallurgy method, and applying electro-deposition coating (co-deposition coating), which consists of nanomaterials (TiO_2 and SiO_2), to identify the changes in hot corrosion, wear resistance, and hardness before and after applying nano-composite coating (co-deposition coating) on turbine blades of AL-Musayyib thermal power stations.

2. Experimental work

2.1. Methodology

Al Mussaib thermal power station is a 1280 MW oil-fired power project. It is in Babil, Iraq, 43.28 km (26.89 mi) northwest of Hilla city center, with coordinates 32° 45′ 1″ north, 44° 16′ 51″ east. The project is presently in progress. The process occurred in several stages. Following the conclusion of the construction phase, the project was officially commissioned in the year 1987. The current proprietorship of the project is held entirely by the Ministry of Electricity in Iraq, with a full ownership stake of 100%. The power station in question operates using a steam turbine. The thermal power project is comprised of four turbines, each with a nameplate capacity of 320 MW.

The methodology of the current research consists of collecting a small sample from broken blades and conducting the XRF to identify the chemical composition of the steam turbine blades. Then, preparing samples with similar composition by powder metallurgy method, which was utilized in the other experimental tests.

2.2. X-ray fluorescent analysis

The X-Ray fluorescence test was performed on broken steam turbine blades (as shown in Fig. 1 (a and b) at the Ministry of Science and Technology. XRF tests are utilized for the chemical composition of powders and alloys. The sample analysis results have been demonstrated in Table 1, with Fe, Al and Cr as optimum ratios.

Table 1
Components overview obtained from XRF test for steam turbine blades and prepared samples.

Elements	Value	
	Steam Turbine Blades	Prepared samples
Na	0.5	–
Mg	0.593	–
Al	11.781	–
Si	1.642	–
P	0.041	–
S	0.268	–
Cl	0.204	–
K	0.056	–
Ca	0.270	–
Ti	0.060	–
V	0.210	–
Cr	9.997	7.461
Fe	73.594	67.961
Ni	0.220	9.703
Cu	0.101	2.835
Zn	0.043	–
Mo	0.420	12.039

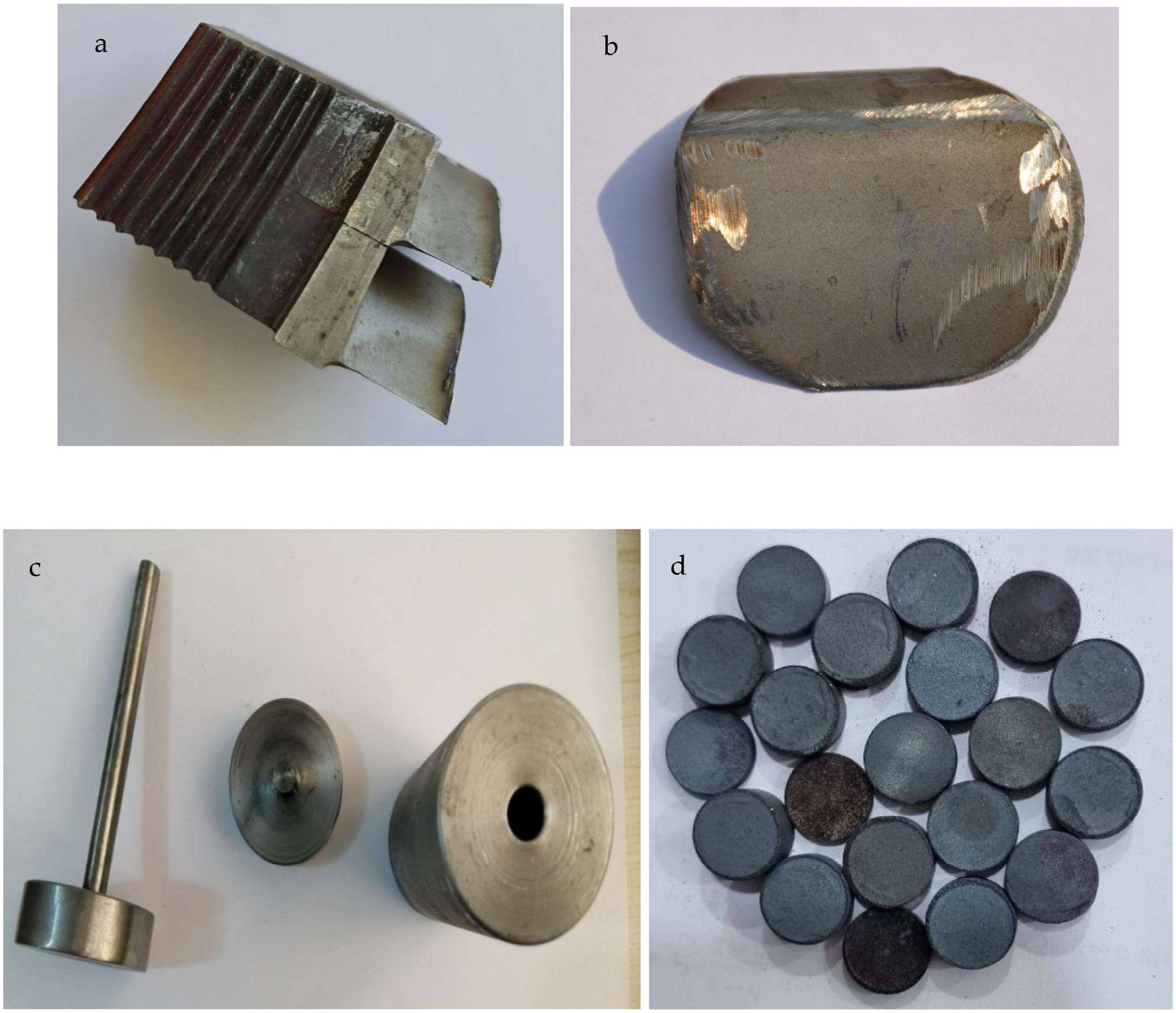

Fig. 1. a) broken steam turbine blades, b) xrf sample, c) the die utilized in sample preparation and d) (13 mm) diameter prepared sample.