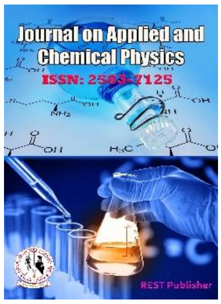
Journal on Applied and Chemical Physics
Vol: 2(1), March 2023
REST Publisher; ISSN: 2583-7125 (Online)
Website: https://restpublisher.com/journals/jacp/
DOI: https://doi.org/10.46632/jacp/2/1/4



Recent Developments in the Field of Thermal Barrier Coatings Solutions for Structural Repair

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Abstract. *The aerospace industry relies heavily on the structural integrity and performance of aircraft to ensure safe and efficient operations. Over time, aircraft structures can experience wear, corrosion or damage due to various factors such as environmental conditions, fatigue or accidents. Structural repairs are necessary to maintain the airworthiness of aircraft and extend their operational life. These brief highlights the importance of coating solutions in structural repair for aerospace. Coatings play an important role in protecting aircraft structures from degradation, preventing further damage and restoring their mechanical properties. In addition, coatings can improve aerodynamic performance, improve fuel efficiency and reduce maintenance costs. The brief discusses the various types of coating solutions used in aeronautical structural repair. These include corrosion-resistant coatings, abrasion-resistant coatings, heat-resistant coatings, and composite bonding systems. Each type of coating serves a specific purpose in mitigating structural damage and restoring the structural integrity of aircraft components. Also, the brief explores the key properties and characteristics of effective coating solutions. These properties include adhesive strength, flexibility, durability, weight considerations, chemical resistance, and thermal stability. Understanding these properties is critical to selecting the appropriate coating solution for specific repair applications. Also summarizes the challenges and considerations associated with coating applications in aerospace structural repair. These challenges include surface preparation, application techniques, curing processes, compatibility with existing coatings and compliance with regulatory requirements. Overcoming these challenges is essential to ensure the successful implementation of coating solutions in structural repair operations. Finally, the abstract discusses emerging trends and developments in aeronautical structural repair coating technologies. These include eco-friendly coatings, self-healing coatings, nano-coatings and smart coatings with sensing capabilities. These developments hold promise for improving the effectiveness and efficiency of structural repair processes in the aerospace industry.*

1. INTRODUCTION

The use of protective coating systems is crucial in preventing corrosion of steel used in wind turbine tower sections. However, inspecting, monitoring, and maintaining these coating systems is a labor-intensive and time-consuming task. This paper presents a novel approach that combines digital technology and a dual concept for monitoring the condition and planning maintenance of surface protection systems in wind turbine towers. The key idea is to utilize an in-situ virtual model to establish reference areas for position monitoring. Additive technologies such as cold spray have seen rapid growth, driven by their advantages over conventional manufacturing techniques. While cold spray offers advantages for heat- and oxidation-sensitive materials, it presents limitations for high-strength and high-hardness alloys widely used in aeronautics, one of the main areas of cold spray application. The purpose of this study, in collaboration with Airbus, was to evaluate the feasibility of using high-pressure cold spraying for structural repair of high-strength and hard-hardened alloys commonly used in aerospace.

2. STRESS CORROSION CRACKING

Stress corrosion cracking (SCC), which can occur in nearly all of the primary alloy systems used in their fabrication, is a serious issue for aeronautical vehicles. Failures due to stress corrosion can have the following effects severe, potentially resulting in the complete loss of an aircraft. Potential and actual environments that may be encountered by primary structures that are most significant to the risk of SCC include the following: Air of varying humidity, containing ground and near-ground environmental pollutants and sea salt aerosols. Potable water and waste water from leaks and spills on man-carrying vehicles and platforms. Condensation of water contaminated with mineral salts[1]. Heat-treated duplex stainless steel (TSS) exhibits Corrosion fatigue cracking (CFC) and stress corrosion cracking (SCC) behavior in chloride and thiosulfate-containing white water from a paper mill. Based on the results of the potentiodynamic and slow strain rate tests (SSRT) performed in this study, it is believed that the fracture investigation to be consistent with an SCC film degradation process where the ion concentrations of the species rise when the paper machine shuts down because of the evaporation of whitewater . Cavitations cracks occur at or close to the borders of ferrite grains, where major metallurgical changes occur following heat treatment. Once cracks form, they spread through fatigue when the paper machine is operating normally and subjected to alternate cyclic loads[2]. pure supercritical water corrosion. Procedures for corrosion tests are outlined in great detail. The given findings and interpretations differ from those obtained in supercritical water oxidation (SCWO) experiments using halides to degrade organic materials. The review will not cover the latter database[3]Stress corrosion cracking service failures, particularly in ductile metals like low-strength ferritic steels, are usually always characterized by numerous cracks. Additionally, information about stress erosion cracks on fracture surfaces, with their wavy tips, suggest that cracks spreading from different centers have eventually converged, occasionally creating a single break that exceeds the fracture threshold. lf, stress corrosion cracking was detected in dynamic structures[4].Realistic stress corrosion crack velocities are not well understood, which makes it difficult to forecast the rate of fault propagation in structures that exhibit stress corrosion cracking (SCC). tension corrosion In monotonic slow strain rate tests (SSRT) anticipated to total failure at typical strain rates and in tests on precast materials with stress intensity levels greater than KIscc, fracture velocities may be significantly higher than those that would occur in service. extremely late phases of a crack's development before it fails to function [5].

FIGURE 1. stress corrosion cracking in aircraft wheel

3. STRUCTURAL HEALTH MONITORING

In order to assess the performance and integrity of composite aircraft structures, structural health monitoring is crucial. Due to its various benefits, fibre optic sensors (FOS) have recently emerged as a reliable method for in-situ real-time monitoring of these structures. It is necessary to take steps and employ strategies to ensure the dependability and endurance of FBG sensors before installing them in composite structures for structural health monitoring. The sensors are typically surface mounted or built within mixing system. Because of the greater fragility of optical fiber, Embedding is more difficult than surface mounting[6].The current state of non-destructive testing of structural components is linked to personnel, This may significantly affect operating expenses. Consequently, the issue is how far. the efforts regarding automation and especially integration and adaptation within structural components or sensitive components can be realized. In smart structures research it is finally also known as structural health monitoring (SHM). ``To invest in building health monitoring technology or not?" can easily be put on a different footing. As long as dCK=dCI > ¡1, it is worthwhile to invest in structural health monitoring where dCK and dCI, respectively, lower investment costs for knowledge/technology and inspections. So getting relevant data will allow you to make a suitable decision [7].Many important and high performance aircraft structures require the use of structural health monitoring (SHM) systems, which boost the structural reliability and safety. System HMM has decreased costs through periodic inspections, which account for about one-third of the overall price of buying and running an aero plane [8].Many important and high performance aero plane structures require the use of structural health monitoring (SHM) systems, which boost the structural reliability and safety. System HMM has decreased costs through periodic inspections, which account for about one-third of the overall price of buying and running an aero plane . In comparison Due to the established "hot spot" location and the relatively small area to be examined, structural SHM of bonded repairs should be much less challenging and more cost-effective than the large structural SHM anticipated for future aircraft applications. In fact, it can be a fantastic route to practice flying and display SHM. Prior to looking at different options, it is crucial to take the SHM system's requirements for the repair into account[9].Active structural health monitoring, or on-demand examination of the structure to assess its condition and project its remaining life, is made possible by embedded ultrasonic technology. Several SHM techniques are being considered or applied in addition to recent developments in relative vacuum monitoring (CVM), and laser Doppler vibrometry (LDV) and fiber Bragg grating (FBG) in aviation and various other sectors (such as wind turbine blades). Six-volume encyclopedia on sensors, different kinds of piezoelectric transducers, and PZT principles utilized in structural health monitoring [10].

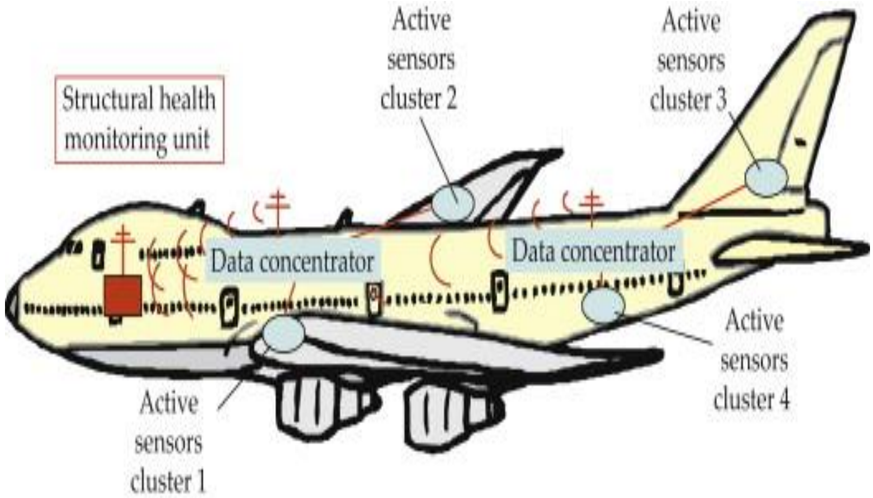

FIGURE 2. Structural health monitoring in airplane

4. THERMAL BARRIER COATINGS

Modern gas turbine engines frequently employ thermal barrier coating systems (TBCs) to lower metal surface temperatures on the hardware in the combustor and turbine section. engines for both land-based industrial power generation and aeronautical jet propulsion are leveraging innovative technology to satisfy rising demands for higher power and propulsion, fewer NOx emissions, and greater fuel efficiency. The combustion The parts of a high-pressure turbine exposed to the highest temperatures are the rotor blades and tip guide vanes initially. Due to the coatings' employment in internal combustion engine and high-temperature gas turbine applications, including abrasive blade tips, thermal barrier coating (TBC) bonding coatings, and turbine shrouds (abrasion and rub tolerance coatings) [11].Since the first documented experiments on turbine blades in a research engine were conducted in 1976, the science and technology of thermal barrier coatings have advanced dramatically. Today some gas turbine engines fly in revenue service with low-risk thermal insulation coatings on the turbine section. . Currently The recommended technique for creating heat barrier coatings is plasma spraying. This method is popular because it may affordably provide long-lasting and replicable coatings when used carefully. [12].In gas turbines, thermal barrier coating systems (TBCs) are frequently employed. insulating covering decreases the metal substrate's temperature, increasing the durability of the component. Alternately, by opening the turbine inlet, fuel efficiency can be raised. A bondcoat layer and an insulating, ceramic topcoat are typically the two layers that make up thermal barrier coating systems. Bond coat mostly consists of metal and serves two purposes. Additionally to strengthening the link between It protects It protects the substrate from oxidation and corrosion between the substrate and topcoat. The two most popular bond coat kinds are MCrAlY, where M is either Ni or Co, and (platinum-)aluminide. An appropriate bondcoat must be selected depending on how the top coat is deposited. Atmospheric plasma spraying (APS) and electron beam physical vapour deposition (EB-PVD) are the two techniques that are used the most frequently. In the 1940s and 1950s, ceramic thermal insulating coatings for gas turbine parts were first developed [13].

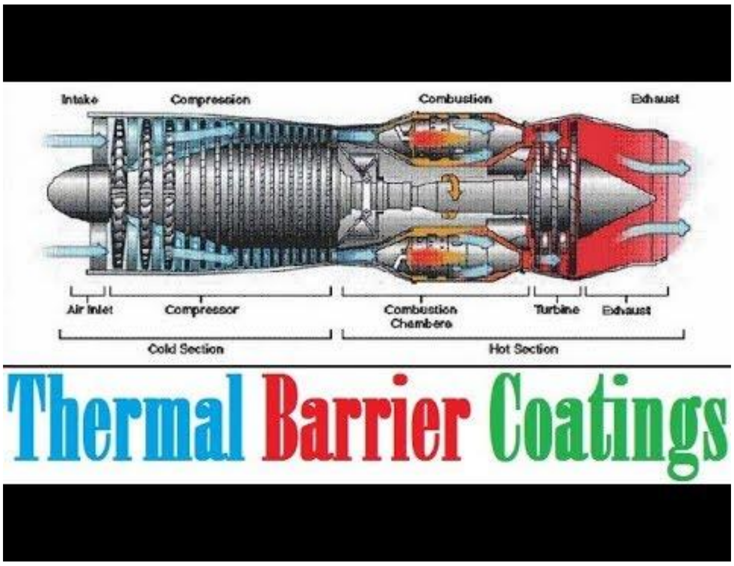

FIGURE 3. Thermal barrier coatings

5. PROTECTIVE COATINGS

Although reviews on this subject can be found in the literature (Cohen, 1995; Twite and Bierwagen, 1998) the authors have tried, in the present section, to condense the main points concerning protective coatings and pre-treatments in use or which have the potential to be used in aeronautics. Nano coatings are not included in this section and will be discussed in more detail . The aviation industry has a significant demand for coatings that are used to paint or repaint the existing structures. Each structure needs many coating layers to provide improved adherence and protection against corrosion and the environment, aesthetic appeal, and other specialized purposes. (1998; Tweet and Bierwagen). Three separate coating layers typically make up a coating system [14]. The protective coating aluminizes the creating a layer of titanium aluminide on thereby acquiring its oxidation under high temperature operations on the surface. But after oxidation, fissures appear. the $TiAl_3$ layer may experience corrosion as a result [222, 223]. One other logical solution is to chrome plate the alloy surface. During oxidation, chromium plating provides Cr atoms, and these atoms move outward along with Ti and Al to form multilayer oxide coatings that obstruct the flow of oxygen [224]. Wei et al. [222, 224] performed plasma surface chromizing on Ti-6Al-4V alloys and examined the alloy's isothermal oxidation behavior at 650, 750, and 850 °C. Bi-polished Wei et al. During oxidation, Cr, Ti, and Al migrate outward to produce multilayer oxide. coatings that prevent oxygen from diffusing. [15].Many Alloys containing a number of essential components are needed for applications where harsh conditions are present. Critical raw materials (CRMs) are becoming increasingly expensive due to their basic and widespread use in high-tech products and applications, as well as the considerable supply risk associated with them, finding possible solutions to save the use of CRMs is critical. , the research highlights that Displacements in aircraft joints may have an impact on how long paint and sealants, which are protective coatings, last. The joint end deformation at exposed sheet ends was predicted using finite element de nodulation in two lap joints connected by counter chunk and dome head fasteners, and the results were confirmed using fatigue tests. The significance of joint displacement on the over coating's ability to prevent corrosion has been outlined in this research. Other areas of the Thermo Mechanical History impact, including additional sites, Future research will evaluate the effects of the load sequence, cumulative damage assessment, inductive adhesion strength, and residual stress. This has an impact on how long aircraft protective coatings last [16]. A Numerous environmental and material design issues, as well as component design ideas and maintenance concerns, have given rise to a broad range of coating procedures. many variants are physical and chemical deposits. Applications for turbine engines include thermal spraying, PVD (physical vapour deposition), and CVD (chemical vapour deposition) [17].

FIGURE 4. Protective coating in aircraft

6. CORROSION PROTECTION

Coatings that are used to paint or repaint the current fleet of aircraft are in high demand in the aerospace sector. Multi-layer coatings are necessary for every vehicle to give other unique features include enhanced adhesion, defence against corrosion and the elements, and aesthetic appeal and reduced maintenance. Three distinct coating layers make up a typical coating system. Substrate pretreatment produces the first layer, a replacement coating. The replacement coat, The second layer of the coating system is typically a very thin (10–60 nm) inorganic layer that enhances adhesion between the substrate and primer and offers corrosion protection. The tasks of the primer, which also comprises a coloured organic resin matrix, are identical to those of the conversion coat. The thickness of a primer application can be anywhere between 5 and 200 mm, but normally only 25 mm (1 mil) is required due to aircraft weight restrictions. The main source of corrosion prevention comes first.

FIGURE 5. coating of corrosion protection paint in aircraft

Chromation and non-chromation pigments are typically included in an epoxy resin in standard compositions. The aircraft is then covered in a top coat, which serves as a significant barrier against external factors including extreme weather and UV rays and gives it decoration and camouflage. The thickness of application for a conventional top coat, which is made with polyurethane resin, ranges from 50 to 200 hours. A full system of coatings consists of pretreatment/primer/topcoat [18].When it comes to maintaining corrosion control in ageing aircraft, finding thus it is also desired to comprehend methods to extend the longevity of corrosion protection around joints. Because the inherent corrosion resistance of alloys is insufficient to protect them from hostile conditions, the safety of these metal parts depends on high-quality paint coatings that act as an environmental barrier. According to Clark, the longevity of the protective coating has a critical impact on the total service life of the damaged area. coating when discussing the forecast of corrosion's impact on structural life. coating, and that the best way to prevent damage is with a well-maintained durable covering. The creation of forecasting technologies for the service life of coatings is essential because coating durability represents an important objective that requires an understanding of the viscous parameters affecting the degradation processes and rate under realistic service conditions [19]. The Electrochemical tests and exposure show the anticorrosive properties of hydrotalcite-pigmented coatings. Additionally, the characteristic changes in the hydrotalcite X-ray diffraction pattern connected to the interchange of decavanadate and chloride are displayed. Additionally, diffraction patterns from coated Al substrates are displayed, proving that corrosion can be stifled by releasing vanadates into an attacking electrolyte via diffraction-based coating inspection. Strong corrosion protection is seen when this happens. When vanadate is released, the HT absorbs chloride or sulphate from the attacking electrolyte, changing the crystal structure that can be seen using X-ray diffraction techniques [20]. Hexavalent chromium-based conversion coatings (CC) offer excellent corrosion protection at a reasonable price. The ambition to There is an urgent need to identify alternative technologies that are more environmentally benign while still giving a comparable level of corrosion protection and adhesion performance in order to provide an industrial "drop-in" replacement for the current methods employing hexavalent chromium. the According to ASTM B117, coatings provide less effective corrosion protection in an SST with 5% NaCl than CCCs do (about 40–120 vs. 500 nm, respectively). (1994, Pearlstein & Agarwala) [21].

7. CONCLUSION

Failures due to stress corrosion can have the following effects severe, potentially resulting in the complete loss of an aircraft. Potential and actual environments that may be encountered by primary structures that are most significant to the risk of SCC include the following: Air of varying humidity, containing ground and near-ground environmental pollutants and sea salt aerosols. The sensors are typically surface mounted or built within mixing system. Because of the greater fragility of optical fiber, Embedding is more difficult than surface mounting. The current state of non-destructive testing of structural components is linked to personnel, This may significantly affect operating expenses. Consequently, the issue is how far. the efforts regarding automation and especially integration and adaptation within structural components or sensitive components can be realized. In smart structures research it is finally also known as structural health monitoring (SHM). land-based industrial power generation and aeronautical jet propulsion are leveraging innovative technology to satisfy rising demands for higher power and propulsion, fewer NOx emissions, and greater fuel efficiency. Critical raw materials (CRMs) are becoming increasingly expensive due to their basic and widespread use in high-tech products and applications, as well as the considerable supply risk associated with them, finding possible solutions to save the use of CRMs is critical. , the research highlights that Displacements in aircraft joints may have an impact on how long paint and sealants, which are protective coatings. Multi-layer coatings are necessary for every vehicle to give other unique features include enhanced adhesion, defence against corrosion and the elements, and aesthetic appeal and reduced maintenance.

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