# Electrodeposited Nickel Based Alloys and Composite Coatings for Strategic Applications – An Overview

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**Abstract:** Electroplating also known as electrodeposition is an important manufacturing process that finds use in a variety of engineering and societal applications. This process involves deposition of a thin layer of metal onto the surface of another object by the application of electric current to enhance the physical properties like wear resistance, corrosion protection, aesthetic appearance etc. This simple and cost-effective process has been adopted by CSIR-NAL for strategic applications like unmanned aerial vehicle, ALH helicopter, engineering applications like automotive and societal applications like solar water heater. The electrodeposited coatings used in these applications will be discussed in detail.

**Keywords:** Electroplating; composite; wear-resistant; corrosion-protection, coating

## 1. Introduction

Electrodeposition has been a popular choice for decades in applications wherein protection against corrosion and wear is required particularly in aerospace and automobile sectors [1]. It finds use in refurbishing of old parts to make them new. It is widely used in the electronics industry apart from being used for aesthetic appearance. Some of the applications of this simple process adopted by Surface Engineering Division of CSIR-NAL are discussed.

## 2. Experimental Details

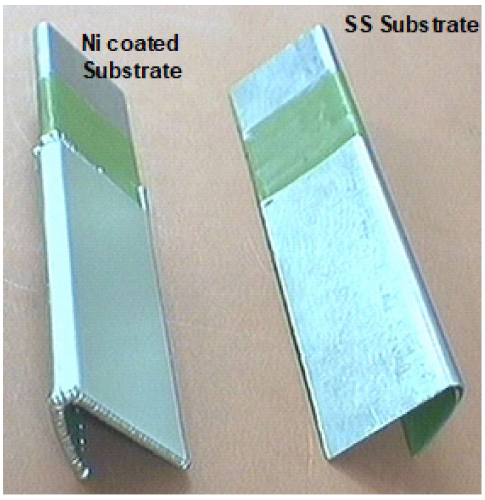
The electroforming and the electroplating of the alloy/ composite coatings are performed using the conventional nickel sulfamate electrolyte whose composition is discussed elsewhere [2]. The size of the ceramic particles used in the composite coatings was typically between 1 to 5 μm while those of the metallic particles was about 100 nm in the high temperature coatings [3,4]. The substrate used for electroforming was SS 316 alloy while the development of wear-resistant coating was on the Al-Si alloy. The high temperature coating development was performed on the Ni Superalloy SuperNi substrate. The Zn-Ni coating was developed using a chloride based electrolyte on Chrome-Moly (CM), Nickel-Chrome-Moly (NCM) and 15-5 PH steel substrates. The developed coatings were characterized using Field Emission Scanning Electron Micrsocope (FESEM), Energy Dispersive X-ray Analysis (EDAX) for the surface morphology and composition respectively. The Ni-Co electroforms were evaluated for their microhardness and tensile strength. The Ni/Ni-Co composite coatings were evaluated for their microhardness and wear-resistance, while the Zn-Ni coating was evaluated for corrosion protection in salt spray environment as per ASTM B117, adhesion strength using cross-hatch test, tensile test and fatigue test. The high temperature NiCoCrAlY coatings were evaluated for their high temperature oxidation resistance.

## 3. Results and Discussion

Erosion-protective coating

Electroforming of erosion protection strips for rotor blades of the ALH helicopter was carried out as an import substitute. The strip required a combination of hardness coupled with ductility to be achieved with a tapering in thickness from 1.2 mm to 0.3 mm (from leading to trailing edge). This protection strip shown in Fig. 1 is required at the leading edges of the rotor blades (main and tail) to prevent erosion and thereby reduce the deterioration of the helicopter blades. Initially stainless steel protection strips were used however, they undergo wrinkling, warping and

cracking for thickness in the range of 0.006 to 0.007 inches.







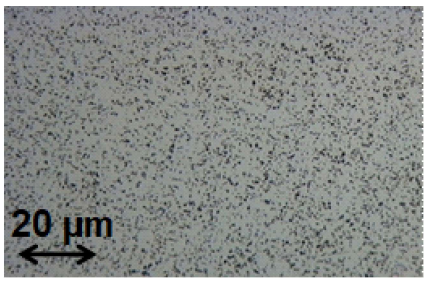
| Location | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|
| Thickness mm | 0.33 | 0.33 | 0.43 | 0.68 | 1.2 | 0.55 | 0.35 | 0.34 | 0.32 |

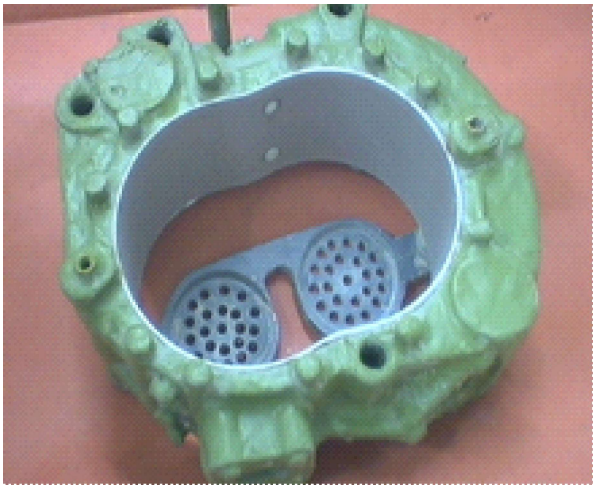
**Fig.1. Electroformed Ni-Co strip 1/8th model of the vertical portion of the tail rotor blade, table depicting the thickness variation from leading to trailing edge.**

However, electroformed Ni erodes at 1/3rd the rate of stainless steel and provides outstanding protection, with no warping or cracking. The high elasticity in nickel erosion strip allows them to be used to stiffen the blades, thereby reducing flutter. The compressive residual stress in the strip helps to increase the blade fatigue life. Erosion protection strips are very much needed for blades made of non-metals like FRPs. The electroforming conditions were optimized to obtain Ni and Ni-Co electroforms with strength >1200 MPa coupled with ductility % elongation 3.5%. The strength and ductility was achieved by optimizing the pH of the electrolyte, electroforming temperature and identifying suitable additive. The tapering in thickness was achieved by deposition on suitably shaped SS mandrel, optimizing the shape of the anode and distance between the cathode and anode. Thus, achieving the mechanical properties with the tapered thickness was a challenging and difficult task. One third model of the erosion protection strip was developed and delivered to HAL with the desired properties.

## Wear-resistant coating

Another strategic application of electrodeposition was in the development of wear resistant Ni-SiC composite coating for Trochoid of Wankel engine, a National mission programme of DRDO (Vehicle Research Development Establishment (VRDE), Ahmednagar) for the Aeronautical Development Establishment's (ADE) NISHANT-Unmanned Aerial Vehicle (UAV). The stator of the Wankel engine i.e. Trochoid was made of Al-Si alloy, a difficult to plate material. As aluminium alloys have poor wear resistance a uniform wear resistant coating was required on the bore of the Trochoid. Ni-SiC coating was chosen due to its good wear resistance behavior [5]. The challenge was to obtain uniform distribution of SiC particles throughout the bore of the Trochoid. A suitable jig was designed, fabricated and used successfully. The obtained coating met the required microhardness and also satisfied the requirement of wear resistance. The coated Trochoids shown in Fig.2 were fitted to the engine and ground test was carried out as per the ADE/RCMA(E) requirements by Propulsion Division, CSIR-NAL. Based on these test results, RCMA (E) granted a provisional flight clearance certificate for testing the NISHANT air vehicle. The engine performed very well in the flight, satisfying all the requirements of the Air Vehicle. After successful testing, *CEMILAC cleared for Limited Series Production of UAV, NISHANT application on 7th Feb. 2013 (RCMA/ENG/WANKEL/100/PC).* This coating has also been tested successfully in the Trochoid of 65 HP and 30 HP Wankel engine developed indigenously by the Propulsion Division of CSIR-NAL.





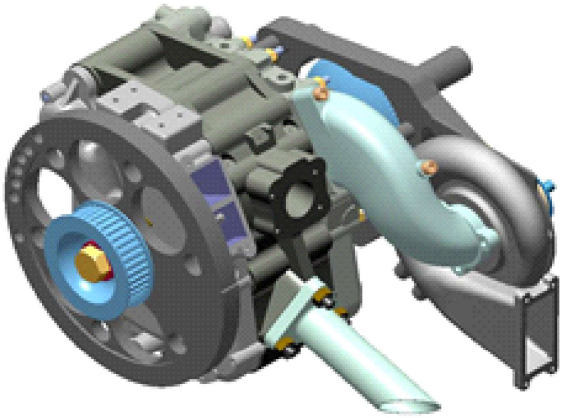


**Fig.2. The cross-section of the Ni-SiC composite coating, Ni-SiC coated Trochoid and an assembled 55HP Wankel engine with the coated Trochoid.**

During the development of Ni-SiC coating, a problem encountered was the embargo on getting the SiC particles of the required size. Also, SiC has a tendency to react with nickel matrix at temperatures > 450°C. Hence, alternate materials were explored and among them the oxide particles were found to be satisfactory. The benefits of the oxide particles are they can be easily synthesized by simple chemical routes and are more stable compared to carbides. Various oxide particles namely alumina ($Al_2O_3$), zirconia ($ZrO_2$), yttria stabilized zirconia (YSZ) reinforced Ni and Ni-Co based composite coatings were developed. The tribological tests on the sample level showed that the performance of Ni-Co-YSZ coating was better compared to Ni-Co-$Al_2O_3$, Ni-Co-$ZrO_2$ and Ni-Co-SiC coatings. The influence of the filler on the wear performance of the coating was studied by interfacing the tribo-tester with the corrosion tester and tribo-corrosion studies were carried out in $Na_2SO_4$ medium i.e in sulphur medium a constituent of fuel. The tests showed that the performance of oxide reinforced coating was better than SiC reinforced coating [6]. Hence, an automobile engine was identified and the bore of the engine cylinder was coated with oxide based Ni-Co composite coatings. The performance of the coated engine cylinder was evaluated by Propulsion Division, CSIR-NAL. The wear results showed that the wear on the cylinder coated with Ni-Co-YSZ (shown in Fig.3) and Ni-Co-$ZrO_2$ was lesser than the other cylinders. The measurement of fuel consumption in an engine was also made and it was observed that the fuel consumption with Ni-Co-YSZ coating showed a marked reduction compared to other cylinders especially at peak engine speed**.** Thus, it was concluded that the performance of Ni-Co-YSZ was better compared to Ni-Co-$ZrO_2$ and Ni-Co-SiC coatings. An Indian Patent No. 394912 has been granted for the same.



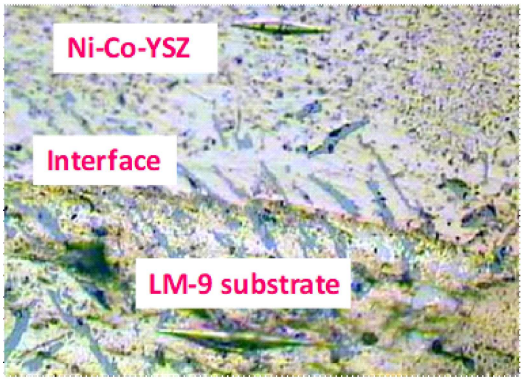



**Fig.3. Ni-Co-YSZ coated automobile engine cylinder, cross-section of the coated cylinder depicting the good interfacial bonding.**

## Corrosion-protective coating

Another application is the development of eco-friendly coatings particularly replacements for the toxic cadmium and hard chrome for aircraft components. The pretreatment procedure was optimized for CM, PH and NCM steels, the electrolyte composition obtain adherent Zn-Ni coating. Adherent, pore free coating was developed and deposition conditions were frozen to obtain Zn-Ni coating with Ni content in the range of 10-16 wt.%. Adherent, pore free Zn-Ni coating was developed. The Zn-Ni coating was passivated with trivalent chrome to enhance the corrosion resistance. The passivated Zn-Ni coating displayed corrosion resistance as per the AMS 2417 J standard i.e., no red rust formation in 500 h. The coating as on date has qualified the tensile, fatigue and hydrogen embrittlement tests. The process has been established for a bath volume of 40 L and production level 500 L for component such as bushes depicted in Fig. 4. The CEMILAC certification of the process is currently underway jointly with ADA Bangalore.



**Fig.4. Zn-Ni coated Bush**

## High temperature coatings

The use of protective coatings is an effective remedy to combat the poor high temperature surface stability of metals and alloys experiencing harsh environments. These coatings are conventionally applied by chemical vapour deposition (CVD), electron-beam physical vapour deposition (EB-PVD), atmospheric plasma spraying (APS) and low pressure or vacuum plasma spraying (LLPS, VPS), detonation spraying (D Gun), high velocity flame/oxy spraying processes. NiCoCrAlY coating was developed through a non-vacuum electrodeposition route using elemental nano-powders. In-depth oxidation behaviour up to a temperature of 1000 $^{o}$C and hot corrosion behaviour of these coatings was studied in $Na_2SO_4$+NaCl medium. The high temperature performance of the NiCoCrAlY coatings was further enhanced by introducing small amounts of reactive oxide namely, $ZrO_2$. Also, in-depth characterization has been carried out to identify the phases formed and surface morphology using characterization tools like FESEM, XRD, X-Ray Photoelectron Spectroscopy (XPS), EDX and Electron Back Scatter Diffraction (EBSD). The high temperature performance of the developed coating was better than the coating obtained using commercial alloy powder [7]. The optimized coating was deposited on a superalloy turbine blade as shown in Fig.5.




**Fig.5. Electrodeposited NiCoCrAlY coating on superalloy turbine blade.**

## Solar-selective coating

An attempt was made to develop environment friendly solar selective coating as an alternative for black chromium. The developed coating had a solar absorptivity in the range of 0.91-0.94 and an emissivity in the range of 0.11-0.08. The coatings were obtained on substrates like brass, copper,

stainless steel and Ni and an Indian patent has been granted for the same IN 286516. Thus, it can be seen that electrodeposition process is exceptionally versatile, simple and can be adopted for diverse applications.

## 4. Conclusions

The elaborate and extensive research carried out at CSIR-NAL shows that the simple electroplating process can provide functional solutions to a vast range of applications.

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