Repair of Metal Coatings Using Environmentally Compliant Brush-plating Solutions

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Cadmium plating is widely used in the aerospace industry for the corrosion protection of steels. Despite the many advantages of cadmium plating, alternatives are required because of the toxicity of the metal and its compounds. One of the criteria used in selecting a replacement for cadmium is that the coating can be repaired *in-situ*, using a technique such as brush plating. This paper presents results of research carried out into the brush plating of steels using zinc-nickel and zinc-cobalt electrolytes. Assessment has been made of the corrosion resistance of brush-plated steel test panels and the use of zinc-nickel and zinc-cobalt alloy plating solutions in the repair of damaged metal coatings.

Metal coatings are widely used on aircraft for the corrosion protection of steel parts, such as undercarriage components, axles, engine mounting plates and steel fasteners. If a metal coating becomes damaged, it is not always possible or desirable to remove the damaged part from the aircraft structure. In this situation, brush (or selective) electroplating is an option because this technique allows *in-situ* repairs.

For aerospace applications, the preferred method of protecting steel parts and fasteners is cadmium, generally electrodeposited from cyanide baths. For military applications in the U.K., cadmium plating is carried out in accordance with Def. Stan. 03-19.[1] The standard protective scheme is illustrated by Fig. 1.

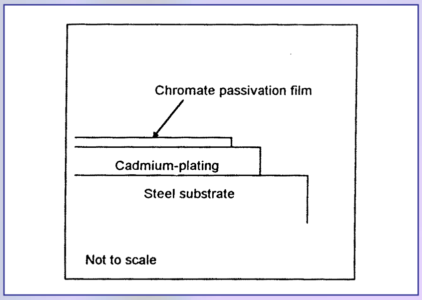

Fig. 1—Standard protection scheme.

For normal requirements, such as the protection of landing gear components, an average coating thickness of 14 μm is used, whereas on threaded items and fasteners, a thinner coating of between 4-7.5 μm is used.

Cadmium plating is widely used because it has a number of desirable properties that have proved difficult to match. These include its good corrosion resistance, sacrificial corrosion behavior toward steels and galvanic compatibility with aerospace aluminum alloys. A further advantage of cadmium is that it may be readily brush-plated, using commercial cyanide-free electrolytes.

The main drawback of cadmium is the high toxicity of the metal and its compounds. Within the U. K., the levels of cadmium permitted in effluent from plating baths have been drastically reduced, necessitating improved treatment facilities, which has resulted in a sharp increase in the cost of plating. Although its use for aerospace applications is still permitted, there are considerable efforts being made to identify suitable alternatives. In selecting a cadmium substitute, a number of criteria must be considered, including repair of the coatings in service.

Brush plating allows the repair of damaged parts using portable equipment. It does not necessarily require disassembly of a multicomponent structure and permits plating of parts too large for standard immersion tanks. The process reduces the amount of masking required and minimizes downtime. The brush plating companies in the U.K. and U.S. have often been at the forefront in the development of environmentally friendly surface treatments because, in brush-plating, the operator is often in close proximity to the workpiece, sometimes in less than ideal conditions. The electrolytes used, therefore, are always designed with health and safety in mind. This extends to cadmium plating where the electrolytes are cyanide-free.

Over the past 10 years, the aircraft industries in Europe and America have evaluated a wide range of metal coatings as alternatives to cadmium plating.[2-5] These include ion-vapor deposited (IVD) aluminum, electrodeposited (ED) zinc-nickel (Zn-Ni) alloy, ED zinc-cobalt (Zn-Co) alloy, and metallic-ceramic coatings that are deposited by spraying or dipping procedures. Of these, it is only the Zn-Ni and Zn-Co alloy coatings that are suitable for brush plating because they may be readily electrodeposited from aqueous solutions, whereas the others listed above may not. The alloying additions of Ni or Co afford a significant improvement in corrosion resistance over zinc alone. In commercial bath plating, the alloys are deposited from environmentally benign acid or alkaline electrolytes, to produce coatings containing approximately 10 - 18 wt percent Ni or 0.8 to 1.2 wt percent Co, compositions that offer a balance between optimum corrosion resistance and economic considerations. The brush plating companies have responded to the developments in alloy plating technology by including Zn-Ni electrolytes on their product lists. The equivalent Zn-Co electrolytes, however, currently do not appear to be commercially available.

Electrolyte Characterization & Coating Preparation

Background

The following section is concerned with the methods used to deposit zinc alloys by brush-plating and the effect of variables such as temperature and voltage on the composition and appearance of the coatings.

Experimental Methods

In this work, brush plating was conducted using four electrolytes. These

Table 1
Brush-plating Electrolytes Employed

Electrolyte		Origin	pH
No.	Type		
1	Zn-Ni	Commercial	8.5
2	Zn-Ni	Experimental	4.5
3	Zn-Co	Experimental	4.2
4	Cd	Commercial	4.2

are shown in Table 1. The electrolytes were either commercial or experimental. According to supplier literature, the commercial alkaline Zn-Ni electrolyte (1) was formulated to provide alloy coatings containing 8-10 wt percent Ni. The experimental Zn-Ni and Zn-Co electrolytes were both mildly acidic and were based on solutions that had previously been used in bath plating to provide alloy coatings in the required compositional ranges.[6,7] The experimental Zn-Ni electrolyte was an aqueous solution of 0.75 mol/L $ZnSO_4 \cdot 7H_2O$ and 0.75 mol/L $NiSO_4 \cdot 6H_2O$, whereas the Zn-Co electrolyte was composed of 1.28 mol/L $ZnSO_4 \cdot 7H_2O$ and 0.22 mol/L $CoCl_2 \cdot 6H_2O$.

In the first part of the study, coatings were brush-plated onto polished 1mm (0.04 in.) thick mild steel test panels of 50 x 50 mm (2 x 2 in.). A relatively simple arrangement was employed for plating and is illustrated by Fig. 2.

The stylus consisted of a carbon block or rod wrapped in cotton wool. The cotton wool was held in position by a porous sleeve (anode wrapping). Prior to plating, the stylus was wired to the power supply and the cotton wool soaked in the electrolyte. The stylus was then brought into contact with the steel surface, which had been degreased in hot trichloroethylene. An electrical current was passed whenever the stylus came into contact with the work piece, and the metal ions in the plating electrolyte were then reduced at the steel surface to form a metallic coating layer.

In each case, the power unit was preset at a value between 4 and 14 V and the electrolytes maintained at a temperature between 20-80 °C, using a water bath as required. Brush plating was then carried out until the desired thickness of coating was obtained (5-25 µm). If necessary, the voltage was adjusted during plating to maintain the preset value. After plating, the power unit was switched off and the coated specimen rinsed in distilled water, followed by acetone solvent, air-dried and then weighed. The brush-plated coatings were not subject to any post-plating surface treatments.

After plating, the weight of each coating was established and the current efficiency (CE) calculated using a method described elsewhere by Lowenheim.[8] The thickness of each coating was established using an eddy-current technique. In addition, samples from each batch of alloy coatings were randomly selected for compositional analysis, using inductively coupled plasma atomic emission spectroscopy.

One aim of this study was to assess whether Zn-Ni or Zn-Co alloy coatings could be used for the repair of coated steel parts. To achieve this, a range of coatings was damaged, then repaired by brush-plating. The following coating types were selected for these repair experiments:

1. Bath-plated cadmium
2. Ion-vapor-deposited aluminum
3. Bath-plated Zn—14 wt percent Ni alloy
4. Bath-plated zinc—1 wt percent Co alloy

These coatings were plated onto both sides of the standard mild steel test panels by commercial plating companies, to thicknesses of 10-18 µm. None of the coatings had been subject to post-plating treatments, except for the aluminum coatings, which had been shot-peened.

The four coating types were damaged by removing a portion of the metallic layer in the center of the test panel, as illustrated by Fig. 3.

After the central portion of coating had been removed, the bare steel was re-plated using Zn-Ni or Zn-Co solutions. The steel was not pre-treated, other than with a final swab with acetone-soaked cotton wool. Plating was carried out on the central portion and, in addition, a 5-µm (0.2 in.) strip of the main coating immediately adjacent to the damaged area (Fig. 3). Brush plating was carried out to achieve a patch-coating thickness of 8 mm. The coating on the overlap region was typically an additional 2-3 µm thicker.

For damaged IVD Al-coated panels, brush plating followed the application of a zincate chemical treatment. This was based on a report by Moskowitz[9] of adhesion problems encountered when brush-plating directly onto aluminum surfaces. The zincate treatment allowed the deposition of a thin, adherent, zinc layer, on both exposed aluminum (coating) and steel (substrate), which then provided a good key for subsequent electroplating. The procedure adopted was as follows:

1. Mask specimen with tape.
2. Treat surface with dilute nitric acid (0.5 mol/L) using cotton wool swab (5 sec contact time).
3. Rinse with distilled water.
4. Treat surface with zincate solution using cotton wool swab (5-10 sec).
5. Rinse with distilled water.
6. Single repeat of stages 4 and 5.
7. Remove masking, rinse with distilled water, then acetone.
8. Air-dry.

The zincate solution was an aqueous solution of zinc oxide (100 g/L) in sodium hydroxide (540 g/L). The masking was applied to the original main coating so that only the bare steel and 5-mm overlap region were exposed. Following the zincate treatment, the masking was removed and brush plating was carried out in the manner described above.

Experimental Results

Appearance

The Zn-Ni alloy and Cd coatings produced under optimum conditions (8 V/ 35-40 °C; see below) were found to be, at best, semibright in appearance whereas the Zn-Co alloys were almost fully bright. The buffing action of the stylus appeared to prevent the build-up

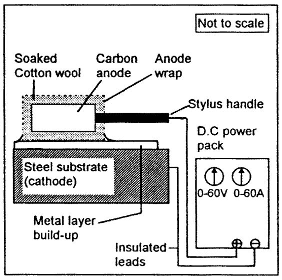

Fig. 2—Schematic of brush-plating equipment

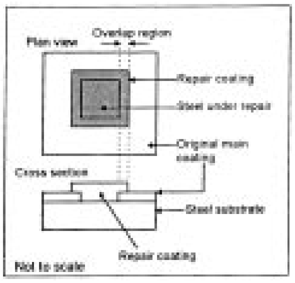

Fig. 3—Schematic of re-plated specimens

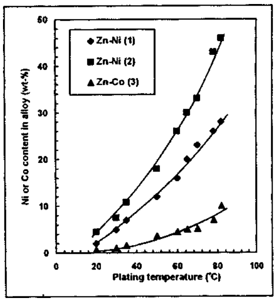

Fig. 4—Effect of temperature on composition

of defects in the coatings and, to the naked eye, the surfaces were flat and defect-free.

Adhesion

A tape test was applied to the coatings deposited onto bare steel substrates, and in each case no signs of adhesion failures were observed. For the simulated repairs, adhesion failures were observed only on IVD aluminum coatings where the zincate treatment was not applied.

Composition & Current Efficiency

For the three alloy electrolytes, the effect of temperature on composition was determined for coatings formed at 8 V, and the results are shown in Fig. 4. The numbers in brackets refer to the electrolyte type (Table 1).

Figure 4 shows that the Ni or Co contents of the alloys were increased as the temperature was raised, which is in accordance with previous studies on brush-plated[9] and bath-plated[6,7,10] deposits. The alloys produced at temperatures outside the 25-45 °C range tended to be dull gray in appearance with a rough surface texture.

The effect of temperature on the CE of the plating processes is shown by Fig. 5 for coatings deposited at 8 V. The CEs of the alloys were found to be mainly above the theoretical maximum of 100 percent. The values found for cadmium were at 90-98 percent over the same temperature range.

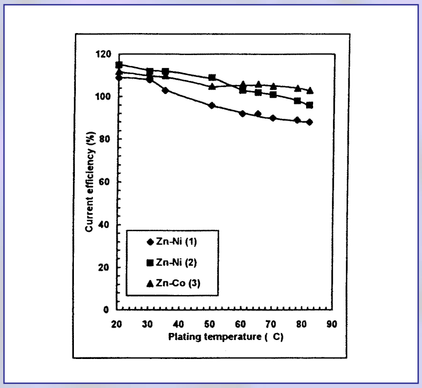

Fig. 5—Effect of temperature on CE

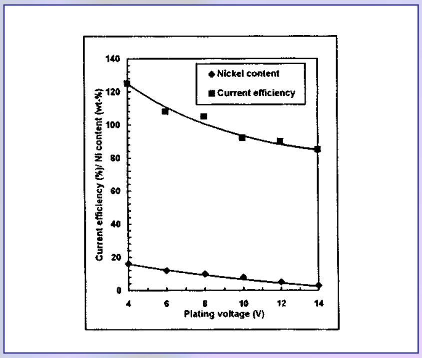

Fig. 6—Effect of voltage on composition and CE

Effect of Voltage

The voltage applied during brush plating was also found to affect the composition and current efficiency of the alloy coatings. This effect was most pronounced for the commercial Zn-Ni alloy (electrolyte 1) and the data obtained are shown by Fig. 6 for coatings produced at 40 °C.

Although voltage had a relatively mild effect on composition and CE, it was found to markedly influence the appearance of the coatings. At high voltages, above 8 V, the coatings were rough and susceptible to dendrite formation, regardless of the plating temperature. Although coatings formed below 8 V were free of dendrite build-up, there was no practical advantage in operating at these voltages because the only noticeable effect was to reduce the rate of coating formation.

Corrosion Studies Background

The ability of a metal coating to protect a steel substrate in, for example, a salt spray chamber, is related to two main attributes of the coating: First, its barrier properties, and second, its sacrificial properties.[5] Once both barrier and sacrificial properties have been completely lost, the steel is free to corrode, forming the characteristic iron-oxide (Fe_2O_3) corrosion products (red rust). In this part of the study, an attempt has been made to separate out the barrier and sacrificial properties of the coatings through the use of electrochemical techniques. Their overall corrosion behavior was then examined, using neutral salt fog tests.

Experimental Methods Corrosion Current Measurements

The barrier properties of a coating can be assessed by measuring its corrosion current density, i_{corr}, in the environment of interest. In general, the lower i_{corr} is, the better a coating's barrier properties will be, provided that it does not contain gross defects.[5] In this study, the i_{corr} values of the brush-plated coatings were determined using the electrochemical-linear polarization resistance (LPR) technique.

The LPR equipment and specimen preparation techniques used have been described in detail elsewhere.[11] The coating thicknesses were >20 µm to ensure that the substrate was not exposed during the test. Each coating test electrode was immersed in quiescent (static) 600 millimole (mmol/L) NaCl solution at 25 °C. The electrode was then polarized by ± 10 mV at a rate of 0.1mV/sec, about its open-circuit corrosion potential, E_{corr}, at 24-48 hr intervals, over a period of 500 hr. The slope of each linear polarization sweep obtained was calculated, giving the polarization resistance, R_p. The value of i_{corr} was then calculated from R_p using a modified form of the Stern-Geary equation:[11]

$$i_{\text{corr}} = \frac{b_a}{2.3\,R_p}$$

where, i_{corr} is in units of µA/cm², b_a is the anodic Tafel constant, mV/decade, and R_p is in units of Ω/cm². The b_a values for Cd, Zn-Ni and Zn-Co alloys were 18.5, 25.2 and 16.2 m V/decade respectively, and were derived from full potentiodynamic anodic polarization sweeps.[11]

Table 2
E_{corr} Data for Brush-plated Coatings at Various Immersion Times

Time (hrs)	Zn-Ni (1)	Zn-Ni (2)	Zn-Co (3)	Cd (4)
10	-0.87	-0.92	-1.00	-0.76
100	-0.81	-0.86	-1.02	-0.75
200	-0.71	-0.84	-1.02	-0.75
300	-0.67	-0.71	-0.95	-0.75
500	-0.62	-0.69	-0.87	-0.75

Corrosion Potential Monitoring

The sacrificial properties of a coating can be investigated through monitoring of E_{corr}.[5,11] In the current work, E_{corr} measurements were taken for the specimens immediately prior to each LPR sweep. The reference electrode employed was a saturated calomel electrode (SCE).

Neutral Salt Fog Tests

These tests are widely used to assess the corrosion resistance of coated steel parts. In this study, the end-point of the salt fog test was taken as the time to the formation of the first significant red-rust spot, abbreviated to T_{RR}. The value of T_{RR} will approximate to the time taken for the loss of both barrier and sacrificial properties. In the current work, the salt fog tests were carried out in a test cabinet, in accordance with ASTM B117.[12]

Table 3
Compatibility of Brush-plated Patch Repair Coatings with Main Coatings

Main coating	Patch coating	ZT	Galvanic corrosion at interface	
			On main coating	On patch coating
Cd	Zn-Ni (1)	X	0	0
	Zn-Co (3)	X	0	2
Zn-Ni	Zn-Ni (1)	X	0	0
	Zn-Co(3)	X	0	1
Zn-Co	Zn-Ni (1)	X	1	1
	Zn-Co (3)	X	0	0
IVD Al	Zn-Ni (1)	X	Patch adhesion failure	
	Zn-Ni (1)	✓	0	0
	Zn-Ni (2)	X	1	1
	Zn-Ni (2)	✓	0	0
	Zn-Co (3)	X	2	1
	Zn-Co (3)	✓	1	1

Experimental Results

Corrosion Current Measurements

Figure 7 shows the variation in i_{corr} with time for the range of brush-plated coatings evaluated in 600 mmol/L NaCl. Over the initial period of immersion, the lowest corrosion rates were found for Cd, which was relatively stable in the saline solution. In contrast, the corrosion rates of the Zn-Ni and Zn-Co alloys were found to decline during immersion.

Corrosion Potential Monitoring

Table 2 shows the E_{corr} values obtained for coatings in quiescent 600 mmol/L NaCl.

Table 2 shows that the potential of Cd was relatively stable in the saline solution, reflecting its near-constant i_{corr} trace (Fig. 7). In contrast, the Zn-Ni and Zn-Co alloys became less electrochemically active (*i.e.*, more noble) with time, a phenomenon that also appeared to mirror the observed decline in i_{corr} for the three alloy coatings.

Previous work has established that the E_{corr} of mild steel is -0.710 V (SCE) in 600 mmol/L NaCl solution.[13] Table 2 shows that Cd was consistently negative to this value, confirming its sacrificial nature. The ennoblement of the Zn-Ni and Zn-Co alloys suggests that these coatings would become less sacrificial with time. Whereas for the Zn-Co alloy, the ennoblement effect was relatively mild; for the Zn-Ni alloys it would probably be sufficient to cause a loss of sacrificial properties over period of 200-300 hr.

Neutral Salt Fog Tests—Undamaged Panels

The corrosion resistance of the brush-plated coatings was assessed by measuring T_{RR} for a range of coating thicknesses, the relationship between these variables being shown by Fig. 8.

The highest levels of protection were obtained for Cd, except at the low thicknesses where the Zn-Co alloy was at least as effective. The Zn-Ni alloys evaluated were less effective than Cd or Zn-Co alloy, with the Zn-10 wt percent Ni alloy deposited from the acid solution being more protective than the Zn-8 wt percent Ni alloy deposited from the alkaline solution.

Neutral Salt Fog Tests—Simulated Repairs

The aim of this part of the study was to evaluate the possible use of the brush-plated Zn-Ni and Zn-Co alloys for the repair of bath-plated zinc alloy coatings (Zn-Ni and Zn-Co), IVD aluminum, and bath-plated cadmium.

The re-plated panels, of the type shown in Fig. 3, including those which had been zincate-treated (ZT), were exposed to neutral salt fog for a period of 168 hr and then inspected for signs of galvanic corrosion at the edge of the 5-mm overlap between the original main coating and the brush-plated repair patch coating. The level of galvanic corrosion was rated on the main coating and repair patch coating, as follows: 0=no galvanic corrosion 1=moderate galvanic corrosion, 2=severe galvanic corrosion. The results obtained are shown in Table 3. The electrolytes used to deposit the patch repair coatings are shown in brackets, along with any evidence of patch adhesion failure prior to exposure.

When re-plating a metallic layer with a coating of a dissimilar metal, there is always the risk that damaging galvanic interactions may occur at the interface between the two coatings. Table 3 shows that the Zn-Ni alloy coating was the most compatible with the four main coatings investigated. In contrast, the Zn-Co alloy was less compatible, particularly when plated onto IVD Al. The galvanic corrosion on the IVD Al coating was observed as a distinct band of dense pitting corrosion around the overlap, beneath a layer of gelatinous corrosion products. For the Zn-Co alloy, a band of white corrosion products was observed next to the overlap, which may have been the result of increased galvanic activity. For this repair, after longer exposure (380 hr), red rust started to bleed from the interface, showing that the patch had broken down. The zincate treatments were found to reduce galvanic effects.

Discussion

Brush Plating of Alloy Coatings

In the current work, the deposition of Zn-Ni and Zn-Co alloy coatings was readily achieved using standard brush-plating methods. It was found that certain plating parameters had a significant effect on the alloy composition. These can be largely interpreted by considering the deposition mechanisms of Zn-Ni and Zn-Co alloys.

The mechanisms of electrodeposition of alloys formed between zinc and the iron-group metals (Fe, Co and Ni) are examples of anomalous co-deposition, as defined by Brenner in his 1963 treatise.[14] In anomalous co-deposition, the deposition of the iron-group metal in acid solution is suppressed by the formation of zinc hydroxide, $Zn(OH)_2$, and related species, at the cathode surface, causing the preferential deposition of Zn, to form a Zn-rich alloy layer. The $Zn(OH)_2$ is chemically precipitated and its presence in alloy coatings (Zn-Ni and Zn-Co) can account for up to 20 percent of the total coating weight.[6] This phenomenon accounts for the current efficiencies being recorded in the current work, which apparently exceeded the theoretical maximum (Figs. 5 and 6).

Figure 4 showed that the compositions of the alloy coatings were sensitive to temperature. This effect relates to the relative rates of zinc and iron-group metal electrodeposition. Previous work at DRA Farnborough[6] has shown that the rates of Ni or Co electrodeposition are strongly influenced by the presence of $Zn(OH)_2$ on the cathode surface. An increase in electrolyte temperature tends to decrease the con-

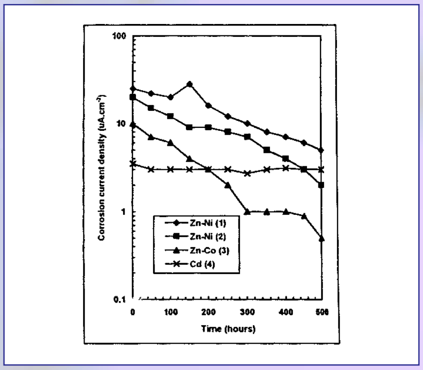

Fig. 7—Corrosion current density-time traces

centrations of $Zn(OH)_2$, thereby increasing the rate of Ni or Co deposition and raising the levels of these more noble metals in the alloy coatings. The lower levels of $Zn(OH)_2$ in the coatings as the temperature was increased also accounts for the gradual decrease in apparent CE observed in Fig. 5.

Corrosion Behavior

Barrier properties

The i_{corr} measurements showed that the lowest corrosion rates were found for Cd and the Zn-Co alloy, suggesting that these coatings would have superior barrier properties over the Zn-Ni coatings. In the neutral salt fog environment, it has been shown that, in simple terms, the barrier properties of metal coatings predominate over the sacrificial properties.[5] In the salt fog environment, it is the coatings with the lowest i_{corr} values that will afford the highest levels of protection, accounting, on this basis, for the trends observed in Fig. 8. For the two Zn-Ni alloys, the coating containing 8 wt percent was less protective than the 10 wt percent alloy. This is consistent with observations made for bath-plated coatings where, for Zn-Ni alloys on steel, the level of corrosion protection in salt fog is known to improve as alloying additions are raised, up to a peak for alloys containing approximately 14 wt percent Ni.[15]

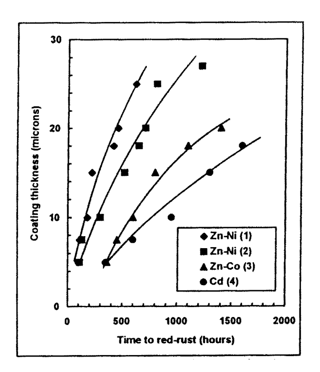

Fig. 8—Effect of thickness on time to red-rust

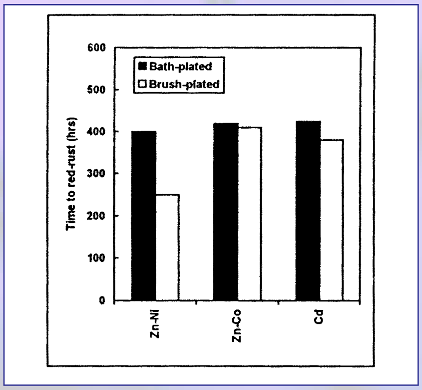

Fig. 9—Comparison of brush-plated and bath-plated coatings in neutral salt fog, for coatings of 8 µm thickness.

Sacrificial Properties

Table 2 showed that the ennoblement of the Zn-Ni and Zn-Co coatings would lead to a gradual loss of sacrificial properties. For the Zn-Ni alloys, the ennoblement effect may, over a period of time, be sufficient to cause a complete loss of sacrificial properties. The ennoblement of zinc alloys has been the subject of many investigations and is usually attributed to dezincification, where the selective dissolution of Zn occurs from the alloy surface.[10,13] The resulting enrichment of the more noble Ni or Co in the surface layers is therefore likely to be responsible for the observed noble drift in potential (Table

2). A further effect of dezincification is that Ni or Co enrichment stimulates the formation of a more protective surface film, causing the barrier properties to improve, and accounting for the steady decline in i_{corr} observed for the alloy coatings in saline solution (Fig. 7).

Comparisons With Bath-plated Coatings

The corrosion performance of the brush-plated coatings can be assessed by comparison with previously published salt fog data for bath-plated coatings. Fig. 9 shows T_{RR} values previously obtained for the following bath-plated coatings: Zn-10 wt percent Ni alloy,[15] Zn-0.8 wt percent Co alloy,[5] and pure Cd,[5] compared with the values obtained in the current work for brush-plated coatings with comparable compositions. For brush-plated Zn-Ni, data for coatings from electrolyte (2) are shown, because they contained appropriate Ni contents and were more effective than those from electrolyte (1).

The performances of the brush-plated Cd and Zn-Co coatings were comparable to their bath-plated counterparts. In contrast, the most effective brush-plated Zn-Ni coating, from acid electrolyte (2), was less corrosion-resistant than the bath-plated alloy with the same alloy content.

Performance of Simulated Repairs

The performance of the patch repairs appeared to be related to the level of galvanic compatibility between the original coating and the patch repair coating. It was found that, where the patch coating and main coating possessed similar E_{corr} values, there was, as expected, no significant galvanic corrosion. For example, where Zn-Ni alloy patches were employed on Cd, there were no signs of preferential attack at the interface. This was because, over most of the duration of the corrosion test, the difference in potential between the two coatings would have been an average of no more than 10 mV despite the instability of the Zn-Ni alloy. In contrast, the average potential difference between Cd and the Zn-Co alloy would have been over 200 mV. In this situation, the more active Zn-Co alloy would have corroded preferentially at the interface and afforded some sacrificial protection to Cd.

Table 3 showed that under some circumstances, the use of Zn-Ni or Zn-Co patch repairs caused corrosion on IVD Al. A simple comparison of E_{corr} values, however, suggest that the A1 layer should have been protected by the alloy coatings. The E_{corr} values of aluminum coatings are often erratic during immersion in saline solutions; however, for IVD Al, a value of -0.75 V (SCE) has been reported.[5] On this basis, the Zn-Co alloy, in particular, should have sacrificially protected the adjacent IVD Al layer because it was negative to the latter, whereas, in fact, the IVD Al layer suffered severe pitting attack. A full explanation of this effect is outside the scope of this study. Previous work[16] at DRA Farnborough, however, has suggested that Al corrosion can be promoted during galvanic coupling with more active coatings because of the formation of highly corrosive alkaline conditions at the cathodic Al surface.

Table 3 indicated that the use of the zincate treatment reduced the damaging galvanic effects referred to above. Further work is required to explain these effects, although one possibility is that the zincate treatment partially insulated the re-plated alloy coatings from the Al layer, thereby reducing the level of damaging current flow across the overlap region.

Summary

This work has shown that steels can be readily brush-plated with Zn-Ni and Zn-Co alloy coatings with controlled compositions. In neutral salt fog tests, particularly encouraging results were obtained for the Zn-Co alloy coatings, suggesting that they are worthy of commercial development and for use in the repair of aircraft parts alongside the more established Zn-Ni system. Simulated corrosion damage and re-plating trials showed that Zn-Co and Zn-Ni electrolytes could be used to re-protect a range of coatings, namely: Bath-plated Zn-Ni, bath-plated Zn-Co, IVD aluminum and bath-plated Cd itself. Some evidence of galvanic interactions were observed when using the Zn-Co alloy in repair situations, although these effects were minimized by the application of a zincate chemical treatment prior to re-plating. **P&SF**

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