



Corrosion effects of runway de-icing chemicals on aircraft alloys and coatings

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ABSTRACT

Corrosion effects of five runway de-icing chemicals on aluminium alloy 2024, magnesium alloy RZ5 and cadmium-plated and subsequently chromate-treated steel 4340 were investigated by cyclic polarisation measurements, open circuit potential monitoring and cyclic chemical exposure tests. The runway de-icing chemicals included in the study contained urea, which has a long history as a runway de-icing chemical, and four new commercial de-icing chemicals, which were based on betaine and potassium formate.

Corrosion effects of urea on aluminium alloy 2024 were more pronounced than those of the new de-icing chemicals. In urea, the breakdown potential, indicating the onset of pitting, was clearly distinguishable in the cyclic polarisation curve and pitting corrosion was detected on the specimen surface after all three types of tests. Weight losses during the chemical exposure tests were also higher for urea than for the other four chemicals, where pitting corrosion was only occasionally detected. The opposite was true in the case of magnesium alloy RZ5: although the alloy experienced general corrosion in each de-icing chemical included in the study, the rate of corrosion was often higher in the new de-icing chemicals than in urea. Corrosion effects of the five de-icing chemicals on cadmium-plated and chromate-treated high-strength steel 4340 were slightly different in all three tests, indicating that differences in coating quality, particularly in the thickness of the coating layers, might have influenced the results. Overall, however, partial loss of the coating layers occurred in all studied de-icing chemicals.

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1. Introduction

In aviation, safe operation of airfields at all times, independently of weather conditions, is of key importance. Accordingly, freezing conditions that may appear under winter weather, especially in Northern countries, necessitate de-icing actions, either mechanical or chemical or their combination, to bring about sufficient friction on the runway. Mechanical de-icing is typically conducted by removing the existing snow and ice by brushing or ploughing, whereas chemical de-icing, performed by spreading a de-icing chemical on the runway, may also be a preventive action to impede ice and frost formation. Chemical de-icing was, in the past, implemented almost solely by the use of urea, but is now often carried out by the means of so-called new de-icing chemicals because of prohibition of the application of urea on runways in several countries due to environmental concerns. The most common formulas of new de-icing chemicals are based on alkali acetates and formates, although recently also formulas based on betaine have been introduced to the market.

The main role of runway de-icing chemicals is to effectively melt and remove ice that has formed and to prevent formation of new ice on airfield runways. However, in order for these chemicals to be applied on runways, they also have to be easily spreadable, chemically stable and environmentally acceptable. Since many of the new runway de-icing salts are corrosive, corrosion inhibitors are added in the commercial de-icing chemicals to prevent or mitigate their possible corrosion effects. Further, before brought to the market, the commercial de-icing chemicals are carefully tested for their corrosion effects on aircraft materials, including aluminium alloys, magnesium alloys and cadmium coatings, according to standard test procedures [1,2]: only chemicals that are non-corrosive pass the test. Nevertheless, despite such efforts to diminish the corrosion effects of commercial de-icing chemicals, practice has proven that after their introduction on runways, the detection of corrosion damage on aircraft components during service and maintenance has become significantly more frequent than before, i.e., during the urea era. One possible explanation is that the standard tests are only short-term and do not necessarily have a good correspondence to the changing in-service conditions that the aircraft materials are subjected to in the field. Therefore, it is obvious that longer-term tests are needed to identify the corrosion effects of runway de-icing chemicals on aircraft alloys and coatings. Moreover, although

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Table 1

Chemical compositions of alloys, wt.%. The compositions are reported as given in alloy specifications.

	Al	Zn	Mg	Si	Fe	Mn	Cr	Other
Al alloy 2024	Balance	≤0.25	1.2–1.8	≤0.50	≤0.50	0.3–0.9	≤0.10	3.8–4.9 Cu
Mg alloy RZ5		3.0–5.0	Balance					0.8–1.7 Ce + La 0.4–1.0 Zr
Steel AISI 4340				0.15–0.35	Balance	0.65–0.9	0.7–0.9	1.65–2.0 Ni 0.38–0.43C ≤0.35 Cu 0.2–0.3 Mo ≤0.010 S ≤0.010 P

corrosion effects of new de-icing chemicals are evidenced during service and maintenance of aircraft components, systematic studies on such effects have received very little consideration.

In this study, corrosion effects of four new commercial de-icing chemicals and urea on aircraft alloys and coatings were investigated using electrochemical measurements and long-term cyclic chemical exposures. The test methods were chosen to provide information on the interactions between the chemicals and the materials under two modes of exposure, i.e., constant immersion and cycles of periodic immersion followed by chemical exposure, to increase the basic understanding on the long-term corrosion effects of the studied chemicals during in-service conditions.

2. Experimental procedures

2.1. Materials

In the following, results are presented for three materials, which are used in fuselage and aircraft components: aluminium alloy 2024, magnesium alloy RZ5 and cadmium-coated and chromate-treated high-strength steel AISI 4340. The alloy compositions are given in Table 1. The aluminium alloy was in T0 condition, i.e., tempered. The high-strength steel was in normalized, hardened and tempered state. The aluminium alloy and the high-strength steel were obtained as 2 mm thick plates, which were cut to specimens of 20 × 20 mm and 50 × 25 mm for electrochemical measurements and chemical exposure tests, respectively. Some of the magnesium alloy was taken from a real aircraft wheel rim, from which the specimens for electrochemical measurements, about 20 × 20 mm in size and up to 5 mm in thickness, were machined. Rest of the magnesium alloy was obtained as 2 mm thick plates, which were cut to specimens of 50 × 25 mm for the exposure tests.

The aluminium and magnesium alloy specimens were wet ground to 120 grit finish using SiC grinding paper and then carefully cleaned in ethanol in an ultrasonic bath to remove any grinding residues. The steel specimens were treated following aerospace material specification AMS-QQ-P-416B [3]. They were first prepared for the coating procedure by sand blasting using aluminium oxide particles. The cadmium plating was carried out electrochemically using a current density of 18 A dm⁻² and a low-embrittlement cadmium cyanide bath, containing 33.5 g l⁻¹ cadmium oxide, 105 g l⁻¹ sodium cyanide and 15 g l⁻¹ sodium carbonate. The plating was conducted at room temperature to achieve a thickness of at least 13 μm. The cadmium-coated specimens were then rinsed with tap water and dried at 110 °C for 1 h, after which they were immersed in a nitric acid solution to activate the surface and, finally, in

an acidic Iridite 8P (MacDermid Incorporation) chromate solution to produce a thin chromate conversion coating.

The runway de-icing chemicals included four new de-icing chemicals, two of which were based on betaine (BetaFrost B+ and BetaFrost C) and two on potassium formate (Meltium and Aviform L50), and urea. The details of the chemicals are presented in Table 2. The new de-icing chemicals were obtained as solutions, whereas urea was delivered as granules. For the tests, urea was mixed with ion-exchanged water to prepare a saturated solution, the concentration of which corresponded to 1080 g l⁻¹.

2.2. Corrosion tests

Corrosion effects of the de-icing chemicals on the test materials were studied by electrochemical measurements and long-term cyclic chemical exposure tests. The electrochemical measurements provide information on the electrochemical behaviour of specimens immersed in undiluted chemicals; this is the situation when fresh chemicals are in continuous contact with the surfaces, such as during taxiing, take-off and landing. The chemical exposure tests, in turn, were used to replicate the cyclic nature of exposure to which the aircraft components are subjected to in practice; they are in contact with fresh chemicals only during taxiing, take-off and landing, while during unloading and loading, overnight parking, maintenance as well as in-flight they are subjected only to exposure of chemical residues that are retained on the surfaces.

Electrochemical measurements were accomplished by using cyclic polarisation and open circuit potential recording methods. In both cases, electrochemical behaviour of the specimens was studied in undiluted or, in the case of urea, in saturated solutions at room temperature. Specimens were prepared by attaching a plastic-coated copper wire with a Leit C (Agar) conductive adhesive on the back of each specimen and then applying two layers of a non-conductive Vinomit lacquer by brushing, to protect the back and the edges of the specimens, exposing only the front to the chemicals. Cyclic polarisation measurements were carried out at a scan rate of 0.5 mV s⁻¹ through a potential range from –800 mV_{OCP} to 1200 mV_{OCP}, using a Gamry Instruments Potentiostat/Galvanostat/Zero Resistance Ammeter model PC3 and a conventional three-electrode cell with a platinum counter electrode and a silver–silver chloride (Ag/AgCl) reference electrode with 3 mol l⁻¹ KCl as an electrolyte. Open circuit potential measurements were performed for 28 days using a silver–silver chloride electrode.

Cyclic chemical exposure tests were carried out using a test procedure that was modified from ASTM F1110 [4] and F483 [5] tests, included in the standard test protocol for the runway de-icing chemicals, and the Boeing test proposal for cadmium-plated parts [6]. Such a test produces more cyclic conditions and provides information on a longer-term basis than the original tests and, thereby, corresponds

Table 2

Details of the runway de-icing chemicals.

Trade name	Main component	Supplier	Components ^a	State	pH	Conductivity, 10 ⁻³ (S cm ⁻¹)
BetaFrost B+	Betaine	Neste Oil Oyj, Finland	Betaine monohydrate 20–60 wt.%, water, corrosion inhibitors	Liquid	8.3	0.0985
BetaFrost C	Betaine	Neste Oil Oyj, Finland	Betaine monohydrate 20–60 wt.%, water	Liquid	8.1	0.00481
Meltium	Potassium formate	Kemira, Finland	Potassium formate, 50 wt.% water	Liquid	11.4	8.87
Aviform L50	Potassium formate	Hydro Formates As, Norway	Potassium formate, 40–80 vol.%, water	Liquid	11.0	9.17
Urea	Urea	Obtained from the airport of Jyväskylä, Finland	20–60 vol.%, corrosion inhibitors 0–2 vol.%	Solid	9.2	0.0177

^a Data provided by the manufacturers, either in the form of operational safety bulletin or technical data sheet.

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