WET CHEMICAL METALLIZATION OF AEROSPACE COMPOSITES AS A LIGHTNING PROTECTION STRATEGY

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Keywords: Polymer composite, Lightning protection, Aircraft safety, Electroless plating, Silver coating.

Abstract

Polymer composite aircraft presently utilize metallic (mostly copper) meshes/foils for lightning strike protection (LSP). However, metallic meshes/foils require additional material for their integration with composites. In this paper, we explore wet chemical metallization of composites via electroless plating of silver. We investigate and report: (i) the effect of the reaction bath on integrity of the composite studied via mechanical analysis, (ii) the effect of bath composition on coating resistivity studied via 4-probe measurements, and (iii) the adhesion characteristics of the coating studied via tape adhesion tests. Although silver is denser than copper, it is less resistive and noble. Wet metallization also offers a quick, effortless means to achieve a continuous surface coating conforming to various geometries. This reduces integration complications and weight, both key benefits during manufacture, operation and repair. It is thus envisaged that with further research, the proposed engineering solution could potentially serve to improve air-travel safety and sustainability.

Introduction

Increased oil prices coupled with the requirements for greener aircraft are driving aircraft manufacturers to adopt composite materials; today's Boeing 787 and the Airbus A350XWB being leading examples. The main advantage of using fiber-reinforced polymer composites (FRPC) in lieu of the conventional aluminum alloys for aircraft structures comes from their high specific stiffness and strength that makes aircraft much lighter and thus more fuel efficient. However, like every technology composite materials also have their disadvantages. One of the major issues with composites is their electrical conductivity, which is far inferior to that of aluminum alloys. However, high conductivity is required to ensure protection again lightning strikes by providing a conducting path for the lightning current. Lightning strike protection (LSP) is thus a necessary feature for aircrafts with composite structures.

The most widely employed LSP strategy is the use of metallic meshes and foils that are placed over the composite. However, in addition to the weight of the mesh, there is also the weight of excess resin used for its binding. Additionally, repair and maintenance scenarios present an even bigger challenge of ensuring electrical conductivity between the new patch of mesh with that existing on the remaining aircraft. For these reasons, aircraft manufacturers are looking at newer technologies such as lightweight, conductive coatings and films that can be externally applied to aircraft structures. With this line of thought, we investigated the possibility of using electroless

coating of silver directly onto the composite surface. Such a technique would have the advantage of providing a simple and reliable means for achieving a continuous coating conforming to different shapes.

Experimental Details

Sample preparation: The coating process [1, 2] was carried out room temperature and atmospheric pressure. Three solutions were first prepared for this purpose.

Sensitizing solution: Tin chloride ($SnCl_2.2H_2O$, Sigma Aldrich) was added to water to make 0.05 M solution. HCl was added until the ingredients completely dissolved.

Tollen's reagent: Silver nitrate ($AgNO_3$, Alfa Aesar) was dissolved in DI water to make a 0.5 M solution. 1 M potassium hydroxide (KOH, Anachemia) was added to the above ($\leq$ 1:20 volume ratio); this generated a reddish brown precipitate. 28% ammonia solution (H_5NO, Alfa Aesar) was gradually added to the above solution until the precipitate was completely dissolved.

Reducing agent: 0.2 wt./wt. dextrose ($C_6H_{12}O_6$, Sigma Aldrich) solution was used to reduce the silver ions to silver. This quantity of dextrose solution was chosen so that it was not a limiting factor in the reaction.

The coating was realized on carbon fiber-epoxy composites through a three-step process as discussed below:

Sensitization: The samples were left undisturbed in the sensitization solution where the tin ions adhere to the surface. After 15 minutes, the samples were thoroughly rinsed in DI water. They were kept with the smoother face up in a container.

Tollen's reaction: Immediately after the previous step, the Tollen's reagent and the dextrose solution were quickly mixed and poured into the container with the composite samples.

Plating: The container was gently rocked to keep its constituents agitated until little after a clean silvery layer appeared on the samples. The samples were then rinsed thoroughly with DI water and were left to dry overnight.

X-ray diffraction (XRD) studies: A Philips X'pert diffractometer was utilized with copper Kα radiation to obtain the diffractograms of the coating in the range of 5 - 90° at $0.5°\cdot min^{-1}$.

Visual characterization: In addition to photography, optical microscopy was carried out to study the quality and continuity of the coating using a Zeiss ScopeA1 AXIO microscope with OCView OptixCam image capture software from Microscope Store LLC.

Mechanical and adhesion characterization: 3-point bending tests were conducted on an MTS Insight universal testing machine with a 1000 N load cell in accordance with ASTM D790 standard [3] albeit using a constant span length of 2.5 in. Adhesion characterization was carried out via the tape adhesion method as per ASTM D3359, procedure B [4].

Electrical characterization: 4-probe electrical measurements were carried out to estimate the coating resistivity. For this purpose, a Keithley 220 programmable current source and a Hewlett

Packard 34401A multimeter (for voltage measurement) were used in conjunction. Ten different currents were injected and the resulting voltage was measured at three different locations. A linear fit of these 10 voltage measurements is made and the resulting resistance at these 3 locations was averaged. A correction factor (CF) based on sample/probe geometry is used to calculate sheet resistance. Specific resistivity was calculated by multiplying sheet resistance with volume density (of pure silver) and coating thickness (assumed as 5 μm).

Results and Discussion

A high resolution photograph of the coated composite is shown in fig. 1. Bare sample is also shown for comparison. A smooth coating with no visually discernible defects was achieved.

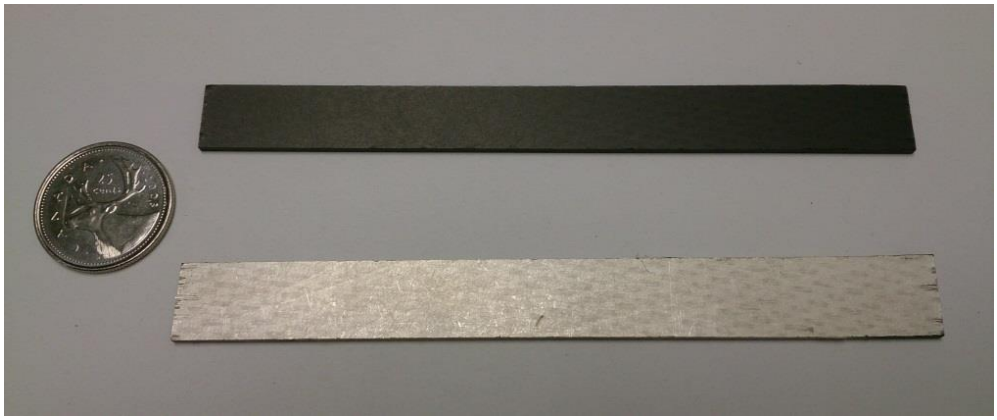
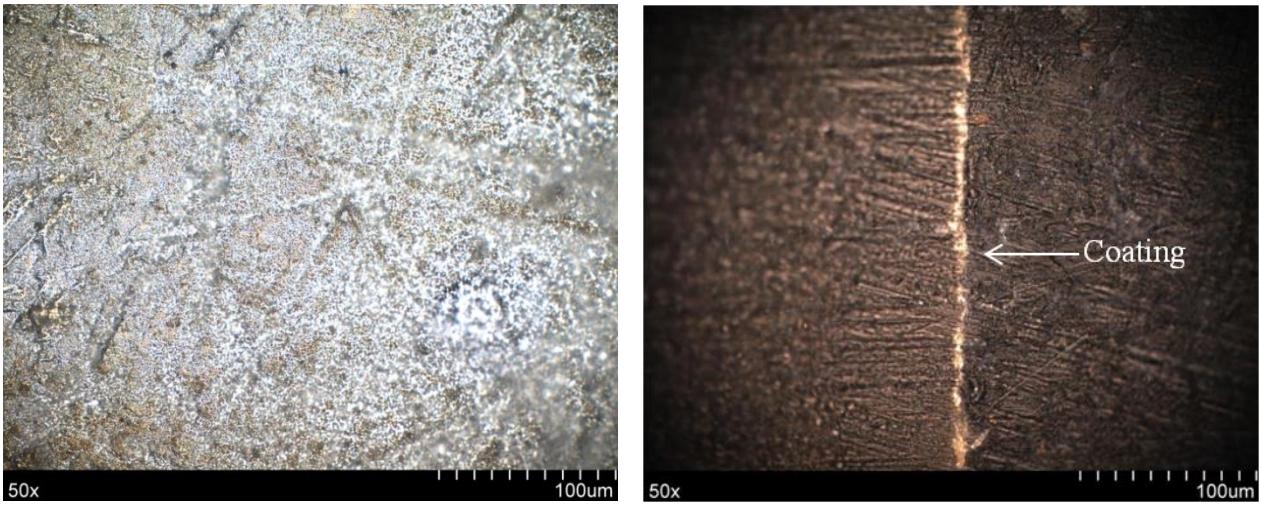


Fig. 1: Photograph of a coated (bottom) and uncoated (top) composite

The coating was further subjected to optical microscopy. Fig. 2(a) shows the face of the coating while fig. 2(b) shows it's cross section. The latter was obtained by sandwiching the coating between the existing epoxy of the substrate (left) and phenocure resin (right). The images indicate a continuous coating with a thickness of less than 10 μm.



(a) (b)

Fig. 2: Optical images of (a) the face, and (b) cross-section of the coating

The coated composites were also subjected to X-ray diffraction studies (fig. 3). Peaks observed at approximately 39°, 45.5°, 65.4° and 78.5° associated with the (111), (200), (220) and (311)

planes are an indicative of the presence of silver, although the peaks are shifted to the higher angle side by about 1° compared to the XRD observations published in the literature [1, 5].

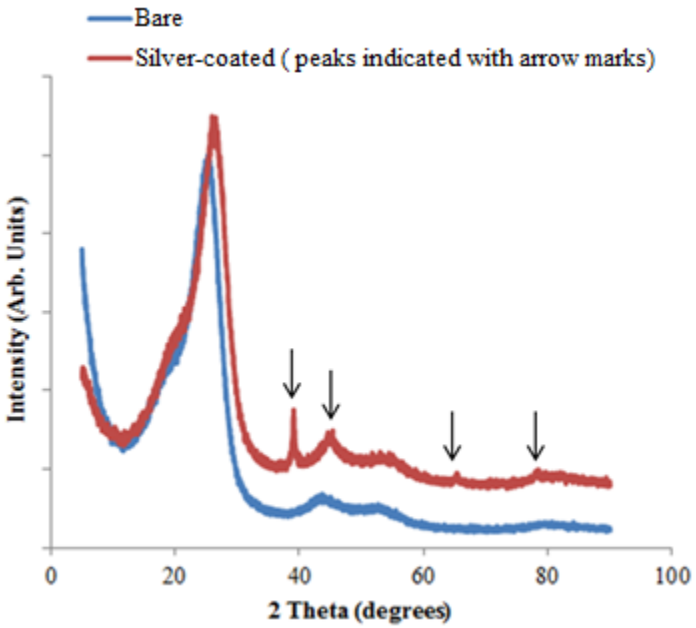


Fig. 3: X-ray diffractograms of coated and uncoated composites

In order to confirm that neither the sensitization nor the reaction bath poses any issues to the sample integrity, 3-point bending tests were conducted; the mechanical characteristics of the coated samples were compared to that of bare samples.

Three samples each were chosen for: (i) sensitization + coating, and (ii) bare composite samples. The average flexural strength and modulus of the coated samples were 100.7% and 102.6% that of the bare samples, the order of the actual values being many 100s of MPa and 10s of GPa, respectively. The flexural properties show no major differences implying that neither of the baths affected the composites adversely.

The adhesion of the silver coating to the composite surface was assessed via the peel-adhesion test. As seen in fig. 4, no flaking occurred after peeling the tape. This intactness of the region between the squares indicates superior adhesion and can be classified as grade 5B.

In the 4-probe technique, a set of four identical, collinear probes were pressed against the sample. Electrical current was passed through the outer probes while the inner probes were used to measure the voltage. An average specific resistivity of $3.695\times10^{-3}\ \Omega\cdot g\cdot cm^{-2}$ was obtained with a standard deviation of 0.424×10^{-3} (about 10%) for the coated composites. This value of specific resistivity is far less good as it is two orders of magnitude higher than that of pure silver. Attempts are underway to investigate the source of this difference with the two immediate considerations being the accurate measurement of coating thickness and its purity. Additionally, coating uniformity and continuity may also be responsible and will be studied.

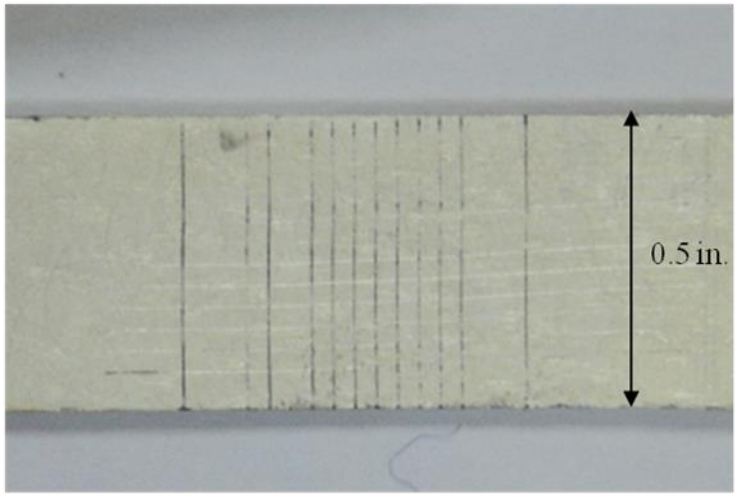


Fig. 4: Cross-scratched surface of the sample after peel adhesion test.

Conclusion

The preliminary results associated with our attempts to directly coat silver onto composites have been presented. Although a successful coating was achieved, the conductivity of the coating was lower than that of pure silver. An examination of this matter is underway. On the other hand, the fact that the chemical processes do not affect composites' mechanical properties coupled with good adhesion characteristics of the coating encourage us to pursue further research on the proposed LSP technology. The prospects of such an engineering technology are that both the environment and the aerospace sector will benefit from improved fuel economy and simpler maintenance and repair protocols in the long run.

Acknowledgements

The authors sincerely thank J. Qian and R. Vernhes of Engineering Physics department for their assistance in optical microscopy and S. Bodkhe of Mechanical Engineering department for carrying out the XRD runs. The composite panels were provided by Bombardier (Aerospace) Inc. This work was carried out as a part of the NSERC CRIAQ COMP-502 project.

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