LIGHTNING PROTECTION OF WET METALIZED POLYMER COMPOSITES

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Keywords: coating, conductivity, damage analysis, lightning protection, polymer composites

ABSTRACT

The aerospace industry is witnessing an increased use of composite materials for aircraft manufacture. The advantage of the lighter weight of composites is shadowed because of their lower electrical conductivity compared to aluminum alloys traditionally used in aircraft structures. Lightning strike protection (LSP) of composite structures has thus become an issue of heightened importance in this industry. Although metallic meshes offer satisfactory protection, they significantly offset the weight advantage of the composites, among other critical issues. We had earlier explored chemical wet metallization of silver as a means of providing a coating of improved electrical conductivity for carbon fiber-reinforced polymer (CFRP) composites. In order to test the lightning protection ability of this approach, two kinds of tests – low energy strikes and resistive heating tests were conducted using separate systems designed in-house. In this paper, we report our qualitative results for lightning tests in terms of damage inflicted to laboratory-level samples. Photography, optical and electron microscopy were thus used to investigate the damage. Whenever possible, these damage characteristics have been correlated with the material properties of the composite and the coating. With further research, wet metallization approach, as a means to realize quick and uniform conductive coating of final composite products could be developed as a viable and sustainable LSP technology.

1 INTRODUCTION

With increased oil prices and improved sensitivity for “green” technologies, various aerospace structures are witnessing a shift from metallic to polymer composite materials. However, composites exhibit low electrical conductivity and this has led to an increased research activity focussing on LSP technologies. While the presently used metallic meshes offer satisfactory protection, they do so at the expense of additional weight, whereas weight reduction was the original driver for a shift towards composite materials. Many materials are being investigated in order to overcome the weight disadvantage [1-6]. We had earlier studied the feasibility of achieving a silver coating over polymer composite surfaces via the traditional Tollen’s process [7]. This process is based on the reduction of the tollen’s reagent by dextrose [8, 9]. In addition to achieving conductive surfaces, the coatings were uniform with good adhesion characteristics. Our preliminary results also indicate that although the tollen’s process is a bath/wet technique, the mechanical properties of the composite are not altered. In this paper, we present our initial results of low energy strikes and resistive heating tests on such silver-coated samples. In both cases, laboratory-designed electrical systems were employed to emulate screening-level lightning currents on samples of interest.

2 EXPERIMENTAL

The low energy strikes were realised using the impulse current emulator capable of achieving a peak amplitude up to 50 kA. In the most basic sense, the emulator relies on directing energy stored in a set of capacitors onto the sample with the spark gap acting as a switch for this operation. For the impulse strike test, a 6 in. × 12 in. sample was mounted into a test fixture that was designed with a square metallic frame forming the return current electrode and a height-adjustable arcing electrode held above the sample as shown in fig. 1(a). The distance between the sample and arcing electrode was maintained at 1.9 ± 0.1 mm. A LeCroy WaveSurfer 422, a 200 MHz oscilloscope was used for recording test data.

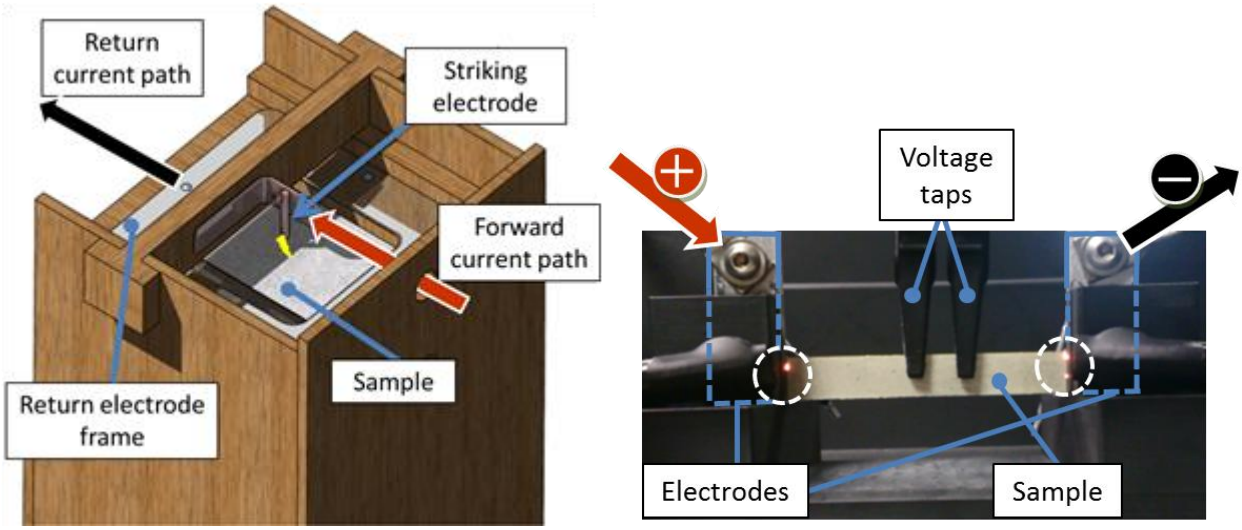
Resistive or Joule heating tests utilised high current power supplies for testing LSP performance against C-component (rectangular) waveforms. The tests were conducted on 5 in. × 0.5 in. coupons clamped with electrodes on either ends (fig. 1(b)). Lambda EMS 150-33-D-RSTL, a 5000 W power supply controlled via LabVIEW® 2013 was utilized to inject different currents into the test coupons.

Optical (Olympus SZX12 fitted with Evolution VF *FAST* color CCD camera from Media cybernetics) and field emission scanning electron microscopy (SEM, JEOL JSM7600F) were used to study the microstructures of the coatings. For the latter, accelerating potential was 10 kV, and a magnification of 10,000× or more were used.

3 RESULTS AND DISCUSSION

As introduced, Tollen's process was adopted to produce micron-scale silver coating on composite samples. Typically, the samples showed a uniform coverage to the naked eye (fig. 5: second from left; also refer fig. 6(a) for SEM image).

Current pulses with a peak amplitudes of 10 (9.6) kA and 20 (19.8) kA were used for the impulse strike test on separate silver-coated samples. The specimen test configuration for the impulse strike tests is depicted in fig. 1(a) and the test waveforms are presented in fig. 2.



(a) (b)

Figure 1: Test configuration of the samples for (a) Impulse current (schematic) and (b) resistive heating tests (photograph)

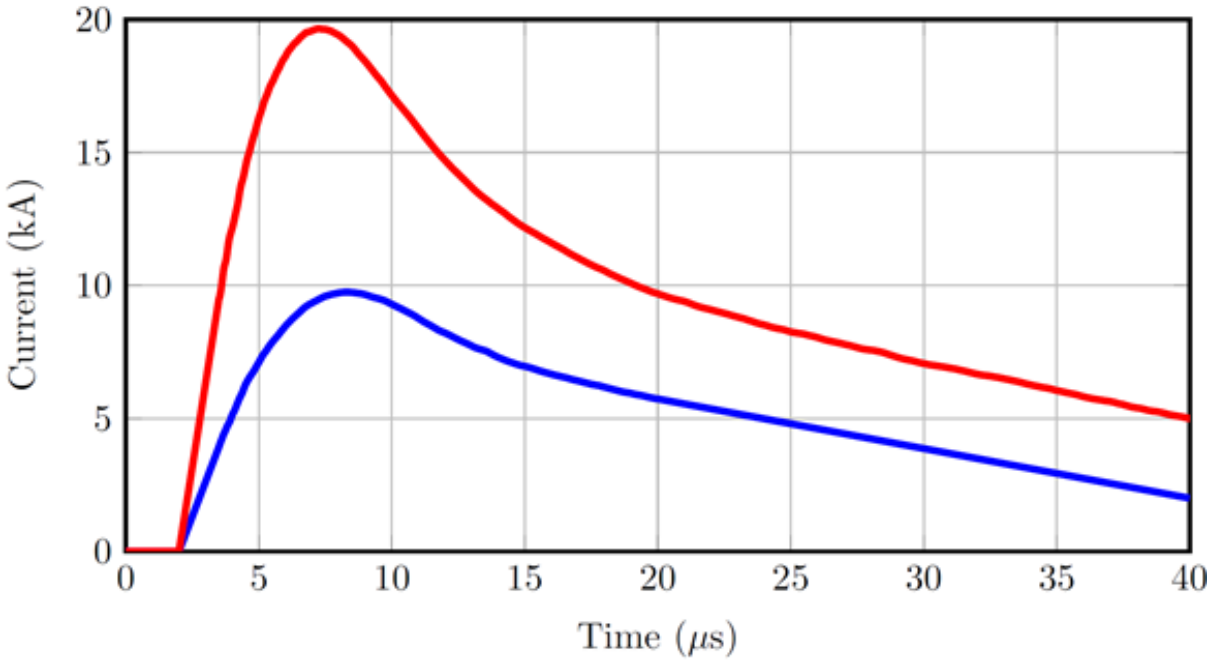
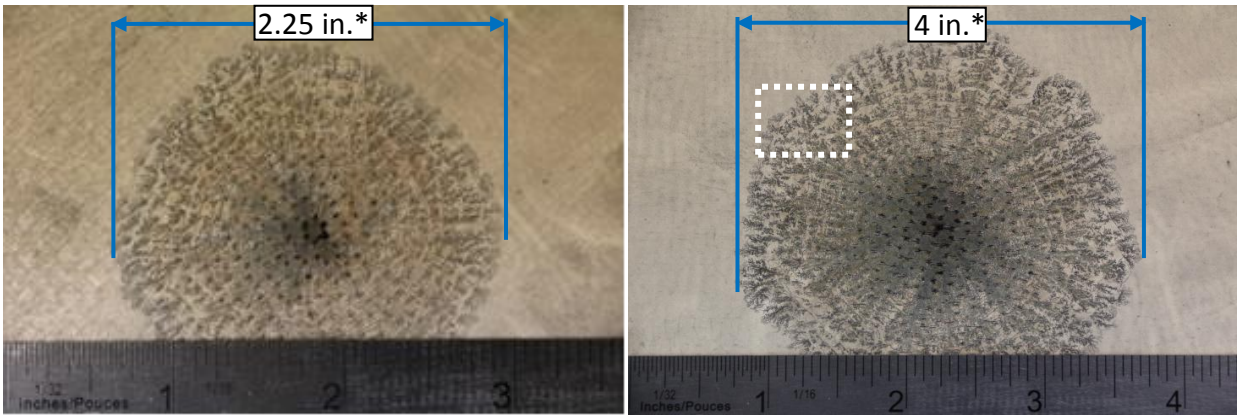


Figure 2: Current waveforms for the impulse strike tests

The impulse strike tests left behind a circular region of damaged coating with a symmetrical spotted pattern of exposed carbon fiber at its core (fig. 3). As one would expect, the 20 kA strike inflicted larger damage, about 1.75 in. larger in diameter, compared to that by the 10 kA strike. In either case, no rear-side damage was observed. The damage in the coating decreased radially outwards from the center of strike with a dendrite-like progression (fig. 4). To draw a comparison, the extent of protection provided by the silver coating at these low energies is similar to that by copper mesh, although silver coating was more sacrificial.



(a) (b)

Figure 3: Photographs of the damage zone after the impulse strike test with (a) 10 kA, an (b) 20 kA (*Maximum dimension; rounded to the nearest 0.25 in.)

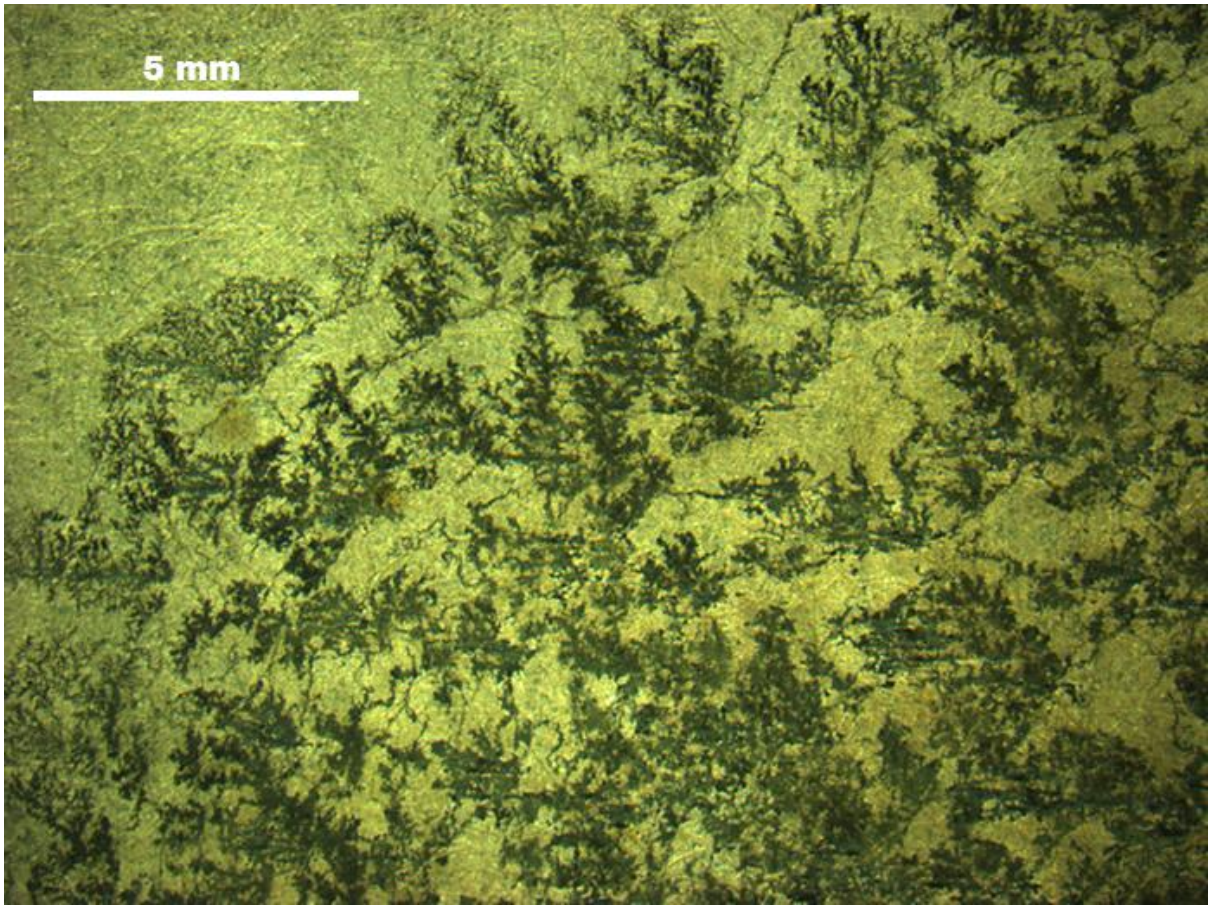


Figure 4: Optical micrograph of the damaged zone after the 20 kA impulse strike
(The location of the above image is shown in fig. 3(b) with a dotted rectangle.)

In order to generate resistive heating, direct currents were injected into the test samples for a duration of 1 s. At 5 A, no changes to the sample were observed. At 25 A, the next current increment, local overheating (hot spots) was observed (dotted circles in fig. 1(b)) at the sample-electrode interface and thus the testing was limited to this value. It is possible that the coatings underwent oxidation leading to a high contact resistance at the interface. Typical samples are shown in fig. 5; no visible signs of damage were observed. However, to have a complete understanding of the damage, it was envisaged to observe microstructural differences between the pristine (untested) and resistively heated samples. For this, a sample (from a different coating batch) that underwent extensive testing (multiple cycles often with higher durations) and that showed a perceptible discoloration was chosen. The observations are reported in fig. 6. It can be observed that the pristine coating is composed of rounded and sub-rounded silver nuclei with a typical size of less than 100 nm and completely covering the sample underneath. The high surface area gives rise to large surface energies. It is speculated that the heat from multiple rounds of current injection led to sintering of the nuclei leading them to fuse into denser aggregates and resulted in restricted paths for current flow. This was corroborated with 4-probe resistivity measurements which showed a 2-fold increase in the resistivity for this microstructure compared to the pristine one.

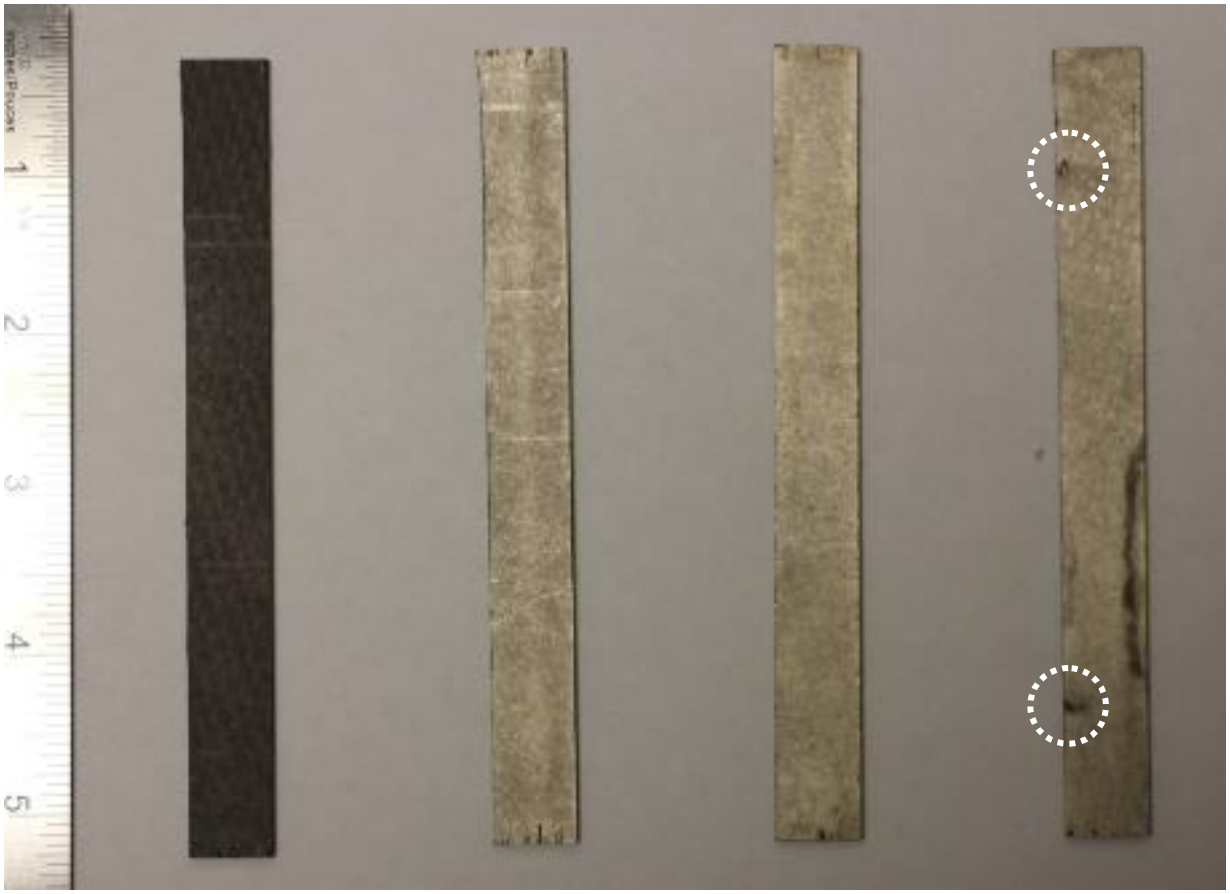
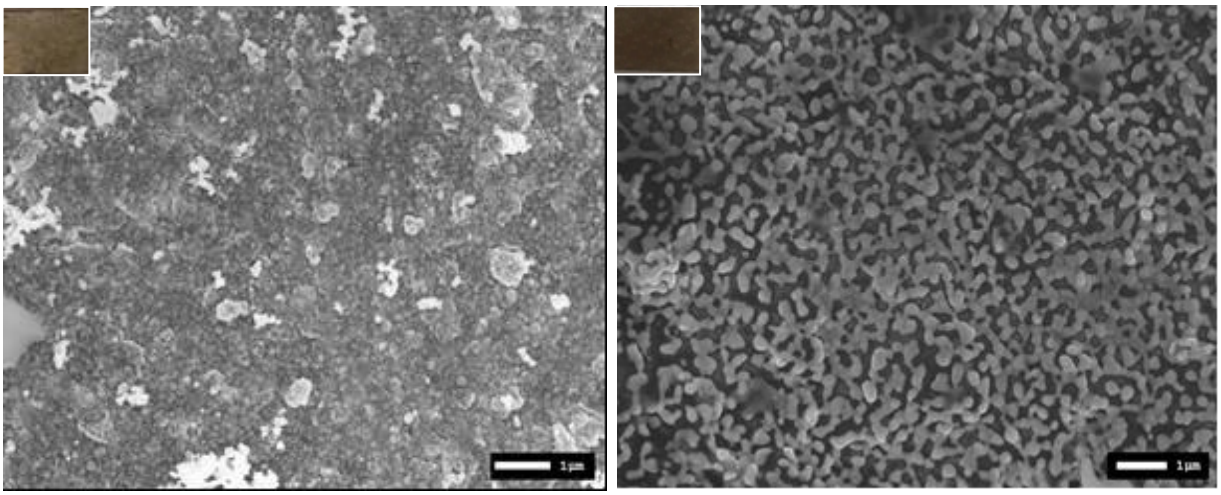


Figure 5: (From left to right) uncoated sample, as-coated sample, sample post 5 A injection and sample post 25 A injection
(Circled regions show burn marks from overheating.)



(a) (b)

Figure 6: SEM images of coating (a) before testing and (b) after many test runs
(The inset shows the photograph indicating the color differences in the sample.)

4 CONCLUSIONS

Preliminary conduction and lightning current screening tests were performed on silver-coated CFRP at two current values each for the impulse strike and the resistive heating tests. The composites survived quite well the screening tests, although as expected the coatings themselves globally deteriorated. The deterioration is particularly strong near the current injection points (material evaporation or hot spots). Besides these results, this work allowed us to establish our test instrumentation and measurement protocol, and provided us with useful information about the coating behavior under test, namely the presence of possible coating oxidation and agglomeration (formation of aggregates) of silver particules due to resistive heating, which instigates a thought in the direction of alternative materials design. Testing with more intrusive parameters is a natural continuation to this work, and will be presented in the future.

ACKNOWLEDGEMENTS

This work was carried out as a part of the NSERC CRIAQ COMP-502 project. The composite panels used in this study were provided by Bombardier (Aerospace) Inc., Montreal, Canada. The authors thank Nicholas Veerabadren of the electrical engineering department for his assistance during the impulse strike tests.

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