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Precipitation-Static (P-Static) Overview of Composite Aircraft

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Precipitation-Static (P-Static) Overview of Composite Aircraft

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ABSTRACT

Aircraft charging due to p-static results from two atmospheric conditions: 1) the vehicle's presence in a thunderstorm, and 2) the triboelectric charging (frictional) caused by neutral snow, rain, or dust particle bombardment of the vehicle frontal surface. Both charging mechanisms can lead to p-static interference by the following mechanisms of charge redistribution: 1) corona discharges from sharp-edged extremities, 2) streamer discharges on dielectric surfaces, and 3) arc over between electrically isolated or intermittently grounded metallic sections.

Corona discharges have spectral energy primarily in the LF through HF region but can have potentially significant energy levels in the VHF/UHF bands. Streamer noise is caused by charge buildup on non-conductive vehicle frontal areas such as radomes and windshields. The spectral energy content of streamer discharges extends beyond the UHF band; but the noise amplitude is low and the potential for RF interference is only a threat if the receive antennas are located close to the streamer discharge source.

An aircraft charged or exposed to fields due only to triboelectric charging may develop corona and limited streamering at its extremities, but it will not trigger lightning. A vehicle such as the B-2 with its large effective area is vulnerable to static charging. The B-2 is thus vulnerable to significant surface static discharge damage if the static discharge system is not optimized. These in-service issues for the B-2 underscore the criticality of a comprehensive design approach with composite materials and finishes to minimize static discharge occurrences.

Materials can be characterized as insulators, static free, or conductor. These are rather broad categories that are defined in terms of ohm/square characteristics. Materials with surface resistivities > 10^{12} ohm/square are likely to develop electrostatic charges which will not bleed off by themselves due to the high electrical insulating property of the surface.

This paper addresses static free materials primarily. Static dissipative composites are, in general, composed of conductive materials such as carbon or metallic particles which are distributed within an insulating medium. The conductive elements are randomly distributed throughout the surface as well as in the bulk portion of the material so that a required amount of volume and surface electrical resistivity are realized. This paper will furthermore provide an overview of material characterization techniques prior to adaptation to a platform and verification techniques after installation.

INTRODUCTION

According to Webster's Third New International Dictionary, triboelectricity is "a positive or negative charge which is generated by friction." Early electrostatic work placed significant emphasis on the relative position of materials in a tribo series. The relative polarity of charge acquired on contact between any material in the series with another was predicted by its location. However, there is little correlation between materials in the series due to the complex nature of the triboelectrification process.

The following parameters play vital roles in determining the polarity and quantity of charge:

- Surface physicals such as smoothness
- Material physicals and chemicals such as morphology, energy level, purity.
- Surface contamination

While all of these parameters play a role in the triboelectrification process, no single parameter or variation of that parameter dominates the total process. For example, PTFE TEFLON sheet has a very low coefficient of friction but is one of the most aggressive tribochargers. The reasons for this are not well understood. A major factor in TEFLON's charge propensity may be related to its polymer composition (Reference 1).

The goal of lab tests was to determine the relaxation characteristics of polymer materials loaded with varying levels of conductive materials. As test results confirmed, homogeneous materials with surface resistivities less

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than 10^{12} ohm/square exhibited acceptable static dissipative characteristics provided the material is bonded to a conductive substrate with no intervening nonconductive layer(s).

With the material and/or coating bonded to a conductive substrate, the static charge will continuously bleed off with no significant accumulation. For nonconducting substrates, static charge dissipation into the air or adjacent surfaces by streamers is most probable. Tests were conducted to simulate both scenarios.

The issue of triboelectric charging addresses primarily the charge transferred to a platform as a result of particles impinging on the platform surface. The critical issue is the charge dissipation with no charge pooling on the platform surface. Materials must be characterized consistently so that the relaxation times for a standard setup are repeatable.

Materials are characterized as insulators, static free, or conductor. This paper primarily addresses static free materials. Static control materials are those which are useful to prevent or minimize the buildup of electrostatic charges on conducting and/or nonconducting substrates. These static materials are essentially of three types:

1. antistatic materials
2. static dissipative materials
3. static conductive materials (Reference 2)

Static dissipative composites are, in general, composed of conductive materials such as carbon or metallic particles that are diffused into an insulating medium. The conductive elements are randomly distributed throughout the surface as well as in the bulk portion of the material so that a required amount of volume and surface electrical resistivity are achieved. This resistivity generally determines the ability the material to dissipate static charge (Reference 2). Surface resistivity contributes to the ability of the material to bleed off any charge which has been transferred by the triboelectrification process. Though it can be expected that electrostatic decay performance would bear a linear relationship with conductivity, this is not verified by test. Some factors contributing to this nonlinear behavior are addressed. The aim of this paper is not to offer detailed explanations for a particular material behavior but to underscore the variety of responses as a function of surface charging.

Creating electrostatic charge by contact and separation of materials is known as “triboelectric charging.” It involves the transfer of electrons between materials. The amount of charge created by triboelectric generation is affected by the area of contact, the speed of separation, relative humidity, and other factors.

Electrostatic charge can be created triboelectrically on conductors the same way it is created on insulators. As long as the conductor is isolated from other conductors or ground, the static charge will remain on the conductor. If the conductor is grounded the charge will easily go to ground.

The objective of this paper is not to develop models that explain the material behavior but to document the variety of behaviors that are likely relevant to the relaxation time of the material.

AIRCRAFT CONSIDERATIONS

P-STATIC OVERVIEW - Aircraft charging due to p-static results from two atmospheric conditions: 1) the vehicle presence in a thunderstorm, and 2) the triboelectric charging (frictional) caused by neutral snow, rain, or dust particle bombardment of the vehicle frontal surfaces.

In the first case, the charging results in a charge separation on the vehicle with a net charge on the vehicle of zero. In the second case, the particles impacting the vehicle deposit charge so that the net charge is not zero.

Both charging mechanisms can lead to p-static interference by the following mechanisms of charge redistribution:

1. corona discharges from sharp-edged extremities
2. streamer discharges on dielectric surfaces
3. arc over between electrically isolated or intermittently grounded metallic sections.

Corona discharges have spectral energy primarily in the LF through HF region but potentially significant energy levels in the VHF/UHF bands.

Streamer noise is caused by charge buildup on non-conductive vehicle frontal areas such as radomes and windshields. The spectral energy content of streamer discharges extends beyond the UHF band; but the noise amplitude is low and the potential for RF interference is only a threat if the receive antennas are located close to the streamer discharge source.

DYNAMIC CHARGING OF MATERIALS - Charging by contact with an electrode at voltage, by induction or by raising the voltage of the sample boundary, are not suitable general methods for surface charging. All these test methods require a flow of charge across the surface from an electrode. This is not appropriate because this charge flow will occur preferentially via the conducting features, and it is not easy to ensure charging of any relatively insulating features, which is where charge tends to be retained (Reference 4).

The rate of migration of static charge is susceptible to such geometric factors as the size of the area charged, the location of the outer boundary to which charge flows, and the proximity of the ground plane. The aim of

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charge-dissipation measurements is to examine what is likely to happen in practical situations. Therefore the test specimen size ideally should be large enough to minimize fringing effects during the test. Size variability was addressed by using either a single discharge electrode or multiple discharge electrodes in close proximity to the material.

The ease of charge migration on materials has traditionally been assessed by measurement of the surface and/or volume “resistivity.” This is not an appropriate approach. A more appropriate approach is to examine material relaxation time.

The migration of charge is affected by the proximity of nearby grounded surfaces. There are two basic extreme conditions: the material is freely supported and is well separated from nearby grounded surfaces, or the material lies against a grounded surface. For these lab tests, the material was either in contact with a ground plane or isolated from the ground plane by means of intervening insulative materials.

The purpose of these material evaluations was to simulate the exposure of candidate materials of various surface resistivites to an aircraft flight environment. In such an environment, the charging phenomena that can be expressed as charging current is determined by the particle concentration, the aircraft velocity, and effective intercepting area of the aircraft. This can be specifically stated as:

$I = (q_p)(c)(v)(Aeff)$

q_p = charge per particle in coulombs

c = particle concentration per meter^3

v = aircraft velocity in meters per sec

Aeff= effective intercepting area of aircraft in square meters

A pre-existing charge on the aircraft, as from triboelectric charging, is not sufficient to cause extended streamer propagation away from the aircraft and development into lightning leaders. Thus aircraft charged or exposed to fields due only to triboelectric charging may develop corona and limited streamering at their extremities but will not trigger lightning (Reference 5).

TEST RESULTS

One can characterize a material independent of its application. Such measurement devices as the Ion Model 210 Charge Plate Monitor (CPM) and ION Model 775 Electrostatic Field Meter accomplish this task efficiently (Reference 6). These devices will characterize the suitability of a candidate material for a static environment.

In conjunction with a Dayton Granger Electrostatic Test Set, the Model 210 can be employed to evaluate a material that is not specifically mounted on the Model 210 charge plate. Charge can be transferred onto the material under test (MUT) either by means of the Model 210 or a remotely charged material can be connected to the Model 210 (Reference 7). The CPM provides the instrumentation to measure the discharge time of a charged, isolated conductive plate in an ionized environment. So this is an adaptation of the CPM, used in conjunction with the Dayton Granger. The primary test approach used the Dayton Granger, the ION CPM and Field Meter to monitor surface voltage, and a high input impedance Electrometer such as the Keithley 610B to monitor leakage current. The Dayton Granger charge voltage was varied from 25KV to 45KV. (25KV is the minimum charge voltage for static discharger efficient operation.) The Dayton Granger static discharger was positioned at 1 inch to 4 inches above the material. If the Dayton Granger is charged to 25KV, the material surface voltage is typically 10KV’s. This was the test limit for the CPM. Sufficient data was taken to verify that the test results are repeatable for these measurement techniques. The test objective was the development of a repetitive technique for characterizing the charge relaxation properties of outermold line (OML) aircraft materials. There were variables that were not completely quantified that have potentially significant impact on the data quality. Further testing is required to more precisely quantify these factors.

Initially the materials were screened on the basis of surface resistivity using a Chomerics Resistance Tester, even though this is an inadequate indicator of material response to electrostatic charging. Generally for commercial and military platforms the OML surfaces exhibit a surface resistivity between 10^6 and 10^9 ohms/square. From p-static measurements on Boeing commercial aircraft, an upper threshold of 10^9 ohms/square is consistent with no RF noise interference with communication systems (Reference 8). Although an attempt was made to correlate the surface resistivity measurements with the static dissipative responses, one cannot correlate these characteristics.

The objective of these static dissipative tests, specifically the relaxation time, was to determine if a MUT was a viable material for OML vehicle applications. (Reference 9) Details on the material technology cannot be included in this paper. Charge dissipation measurements are affected by both surface and bulk phenomena and the mounting fixture. The measured static charge dissipative characteristics of conductively loaded materials were normalized to initial readings. These decay characteristics are expressed as 20 log (V@ t) / (V initial) where V initial is the surface charge voltage and V@ t is the charge voltage as a function of time. Such variables as the Dayton Granger charge voltages and static discharger separation distances from the MUT were shown to be of minimal affect by expressing the decay

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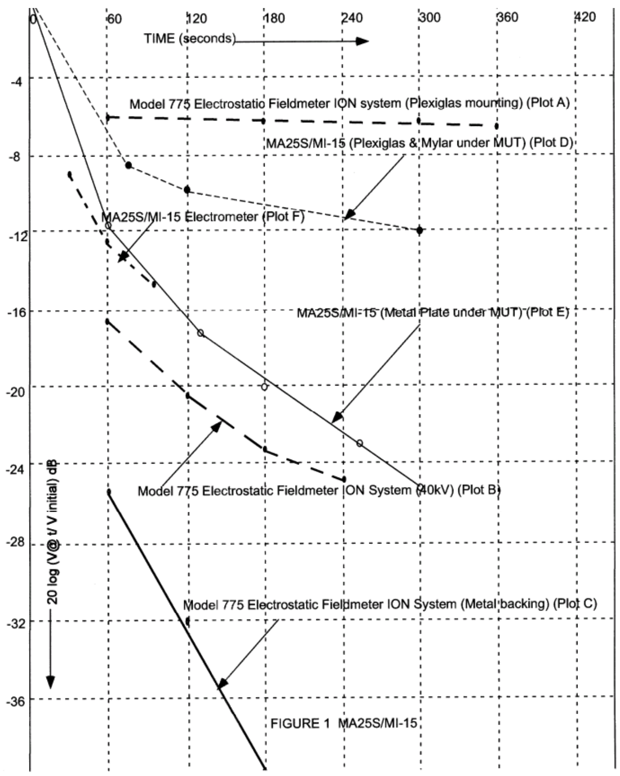
characteristics as a logarithmic relationship between the relaxation voltages at indicted times with the initial surface voltage.

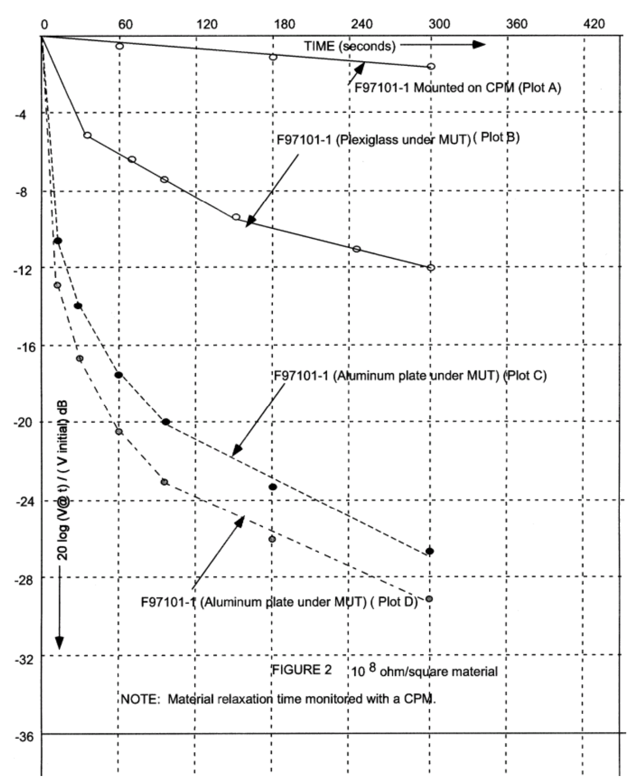
A comparison of the measuring techniques is best illustrated by the data shown on Figure 1 for a MA25S/MI-15 material. Because of the surface texture, the surface resistance measurement were not uniform or repeatable. The substrate material for this evaluation was both an aluminum plate and Plexiglas in order to simulate both a ground plane and insulator condition. The material performance was characterized using an ION CPM, ION field meter, and Electrometer.



The model 775 Electrostatic Field meter placement with respect to the MA25S/MI-15 was reoriented in multiple locations in order to assess probable material uniformity. Plots A, B, and C on Figure 1 are the measurements with the ION field meter. These three plots underscore the criticality of the substructure conductivity in establishing the relaxation time of the MA25S/MI-1

For Plot A, the MUT was isolated from the instrumentation table by Plexiglas. This is equivalent to triboelectric charging with no designed discharge path. Plot B was generated with the MUT lying in direct contact with the table; Plot C, an aluminum ground plane was installed between the MUT and test table, and the aluminum ground plane was separately grounded. Plot's D and E are the relaxation measurements taken with the CPM. For Plot D, the MUT was mounted on Plexiglas with further isolation provided by a mylar sheet; for Plot E, an aluminum ground plane was installed between the MUT and test table. The resulting discharge reflected in Plots D and E is via the CPM and electrical connection between the MUT and the CPM. (The specification for the CPM performance is a maximum of 10% discharge in 5 minutes.) Finally Plot F is equivalent to Plot E except the charge relaxation was monitored on an electrometer.

From an analysis of the data associated with F97101-1 material, Figure 2, and T-249LT material, Figure 3, one will observe several unexpected and unexplained material responses. The F97101-1 surface resistivity was characterized as 10^8 ohm/square and the T-249LT as 10^{12} ohm/square. Both materials were evaluated installed on either an aluminum plate or Plexiglas to simulated conductive and nonconductive substrates. There is a distinctive difference in relaxation times but not of the magnitude expected for such diverse substrate materials. Plot A (Figure 2) characterizes the F97101-1 material as installed on the CPM with the finish surface in contact with the CPM. 5kV was transferred to the F97101-1 via the CPM and the self-discharging response of the CPM verified. In this charge/discharge cycle as reflected in Plot A (Figure 2), the F97101-1 material was isolated from any discharge path via a ground plane or external ionization source. In Plots B, C, and D (Figure 2), the F97101-1 was installed on either an insulator (Plexiglas) or conductor (aluminum) and static voltages were monitored on the CPM via an electrical connection between the MUT and the CPM. The differences in relaxation times between Figures 2 and 3 for the Plexiglas and aluminum are reason for further tests to identify all effects that contribute to these discharge.



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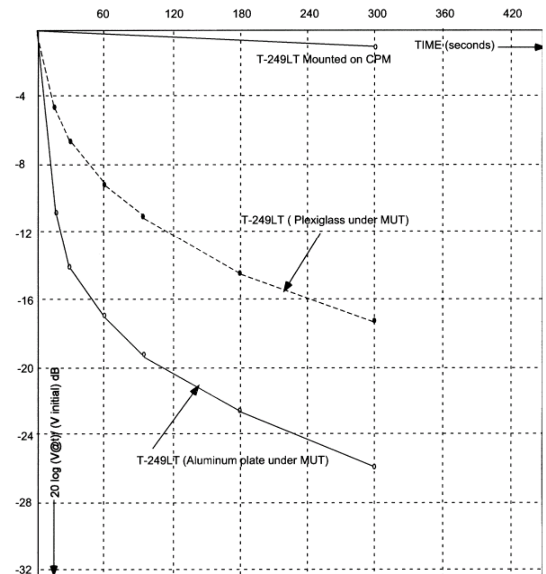

Figure 3 10^{12} ohm/square

NOTE: Material relaxation time monitored with a CPM

In analyzing these measurement variations, the self-dissipation of the CPM was evaluated. The CPM performance was compliant with the requirement that the CPM discharge less than 10% in 5 minutes.

In the static charge test phase, using the Dayton Granger Electrostatic Diagnostic Test Set, copper tape was applied along, at least, two edges of the MUT to establish a ground plane reference interface with the Electrometer, as shown in Figure 4.

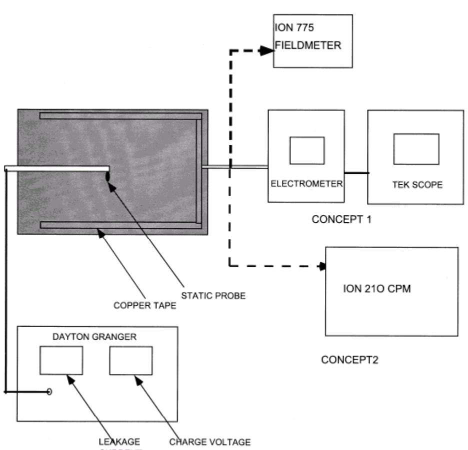

FIGURE 4TEST SETUP FOR MEASUREMENT OF STATIC CHARGE RELAXATION TIME

The Dayton Granger static discharger location with respect to the material was varied from 1 inch to 4 inches. The Dayton Granger charge voltage was varied from 25KV to 45KV's. From the material characterizations, one observes that these relaxation voltage curves varied by as much as 10dB for materials with the same ohms/square values. These graphs, as shown in Figures 5 through 7 are grouped, by surface resistivities, in descending order of resistivity.

A single material with a 10^9 surface resistivity is characterized in Figure 5. The variables addressed in these plots is the Dayton Granger charge voltage and separation distance of the static discharger from the MUT. These variables translated into approximately 2dB worst case variation in the charge relaxation time. Generally the variations are bounded by approximately 0.5 dB. Since this data was all taken within a short time period, the external environment, namely humidity, changed minimally. Thus it was not a factor in data variability. One concludes that this material response is independent of charging voltage.

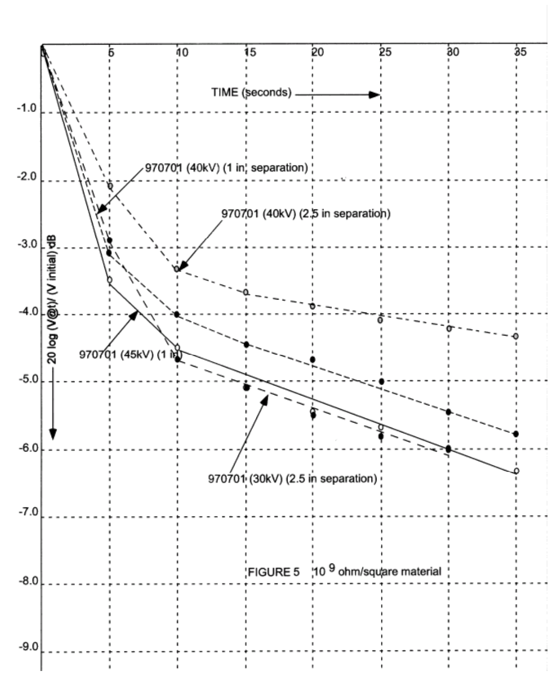

FIGURE 5 10^9 ohm/square material

Two materials with a 10^{12} surface resistivity are characterized in Figure 6. Again the variations with a material are bounded by approximately 0.5 dB regardless of the charge voltage or separation distance of the static dischargers from the MUT. However, there is as much as 3dB variation in performance between the two materials. The steeper the curve; the more rapid the surface charge dissipation; i.e., the relaxation time constant is shorter. Based on the surface resistivity measurements of the 980306 material, one would not predict the observed relaxation time. Using the relaxation characteristics of the 980211-1 material as the baseline for the 980306 material, the 980306 performed better than predicted. The bulk resistivity of the 980306 is superior to the measured surface resistivity. The 980306 was constructed so that the carbon fibers were added internal and adjacent to the adhesive. This construction simulated a dielectric layer as the top layer with a conductive layer adjacent to the adhesive/substrate interface.

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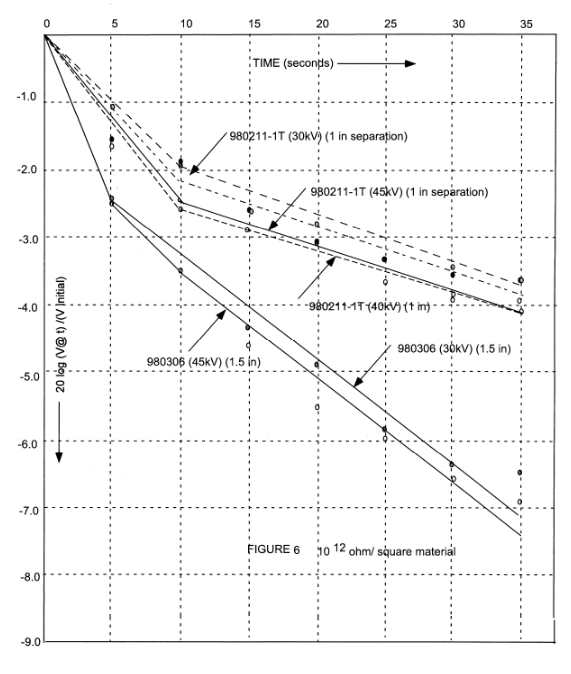

FIGURE 6 10 ^{12} ohm/ square material

In contrast, the fabrication process for the 980307 material was similar to the 980306 except the carbon fibers were installed in the top film. Thus the 980307 surface resistivity was 10^6 ohm/square; 10^{12} for the 980306. The enhanced relaxation characteristics of the 980307 must be due to this lower surface resistivity. Characteristics of two 10^6ohm/square material are shown in Figure 7. The contrast between the MF-244 and 980307 material performances is spotlighted. The two plots probably define the boundary limits for 10^6 material. The MF-244 material relaxation time is marginal based on the 10^9 ohm/square material as plotted on Figure 5.

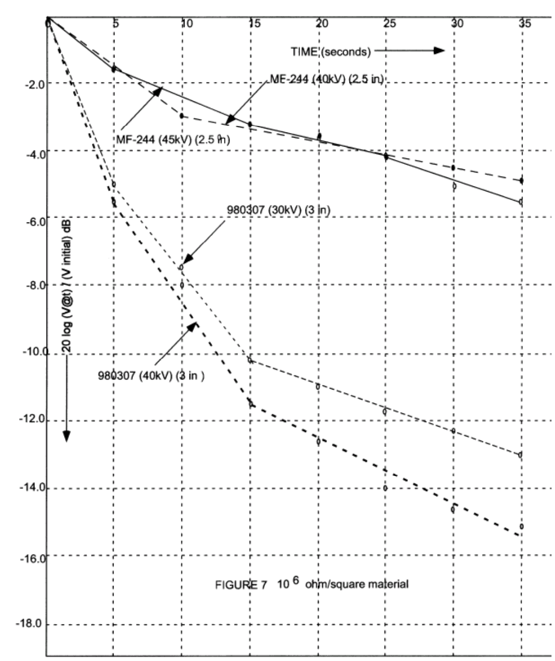

FIGURE 7 10 ^{6} ohm/square material

In conclusion, these materials can be sufficiently loaded with conductive properties such that the static charge decay times do not represent a safety hazard or a source of interference with communication equipment. These resistivity measurements determined that the surface resistivity was sufficiently uniform that charge pooling was not an issue. Thus this instrumentation approach is a reasonable quick look evaluation of the relaxation times for these material . A field meter or equivalent approach is required if the surface characteristics are nonuniform as has been observed on the B-2 OML. If the top coat is a rain erosion material such as polyurethane, then the charge is isolated from the antistatic substrate material.

To reiterate, the MUT's as shown in Figures 5 through 7 were uniformly loaded with conductive fibers. Both the random and ordered surface resistivity measurements confirmed this uniformity. However, as expected, the MUT edges did exhibit some variability in this uniformity. Thus the copper tape bridged such discrepancies as well as established a conductive transition from the MUT to adjacent conductive platform surfaces. This electrical bond between the MUT and copper tape is compromised by several factors including the adhesive on the copper tape and finishes on the MUT. However, since the 3' x 3' sheets could be evaluated only with the nonconducting backing paper intact, the copper tape interface was the only realistic simulation of a reasonable surface discharge path.

CONCLUSION

Even as the triboelectric charging of a material is independent of the surface resistivity, the dissipation of the charge is not wholly dependent on the resistivity. To reiterate, there is not a linear relationship between surface resistivity and surface charge dissipation. Charge density does not decay exponentially, which is the usual situation in electric circuits. Since Ohm's law is rarely valid in highly insulating materials, true exponential decay is not often encountered. Although the initial decay rates are exponential, the amount of charge remaining after some time is always much greater in mobility-dominated materials (Reference 10). Although there may be general agreement between surface resistance and the static decay rate, there is no quantitative formula for predicting one from the other.

While the instrumentation for decay times is not as simple as that for resistivity measurements, the charge decay approach is more appropriate for the assessment of the risks from static electricity. These tests have shown that the decay curve profiles can vary appreciably depending on whether the material is on a conductive or insulative substrate surface.

REFERENCES

1. Proceedings, "Triboelectricity and Surface Resistivity Do Not Correlate," S. L. Fowler

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2. Handbook of Electromagnetic Materials, P.S. Neelakanta, Chapter 20
3. Evaluation Engineering, June 1998, pages 62 thru 69, “How to Select Ionization Systems,” by Arnold Steinman
4. “Investigation of Test Methodology for Triboelectrification,” by William D. Greason
5. Aircraft Lightning Protection Handbook, 1999, F.A. Fisher & J. A. Plumer
6. Model 210 Charge Plate Monitor (CPM) Operation Manual
7. “Alternate Uses for the Charged Plate Monitor,” by William E. Vosteen
   EOS/ESD Symposium 96
8. D409-12315-1, “E-6 Precipitation-Static Test Procedure”
9. “Instrumentation and Standards for Testing Static Control Materials,” by
   John N. Chubb
10. Fundamentals of Applied Electrostatics, by Joseph M. Crowley1988 EOS/ESD Symposium