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Voltage Ramp-rate Dependence of DC Breakdown in Polymeric Insulators: Physical Models versus Data

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DEPENDENCE OF ELECTROSTATIC FIELD STRENGTH ON VOLTAGE RAMP RATE FOR SPACECRAFT MATERIALS

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ABSTRACT

This work investigated the dependence of electrostatic field strength for spacecraft materials on voltage ramp rate, by applying an increasing electrostatic field until electrostatic breakdown occurred.

Tests on the polymeric material Kapton E™ found that at ramp rates two or three orders of magnitude lower than the maximum recommended rate, F_{ESD} was lower than at rapid rates by a factor or two or more- this suggests that tabulated values of F_{ESD} which have been used by the spacecraft charging community can substantially overestimate F_{ESD} in common slowly evolving spacecraft situations. Similar measurements on other polymeric materials have been performed to test three ramp rate model of increasing sophistication.

1. INTRODUCTION

Electrostatic discharge (ESD) can cause serious upsets or failures to space assets and continues to pose a challenge to spacecraft designers and modellers [1,2]. For many real spacecraft charging situations, standard tests [3-4] with rapidly increasing applied fields do not provide an appropriate measure of the likelihood of failures or a precise or accurate determination of F_{ESD} under space-like conditions [5]. ESD is a permanent, catastrophic failure of a dielectric material. Enhanced understanding of prolonged exposure to high static electric fields (DC aging) of insulating materials based on expanded experimental studies is critical to understand the physics of highly disordered insulating materials, as well as its applications in spacecraft charging [6-7].

The primary objective of this work is to test the dependence of electrostatic field strength on voltage ramp rate for spacecraft materials by applying an increasing electrostatic field until electrostatic breakdown occurs.

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2. THEORY

The data from these and past tests for the polymeric materials polyimide (PI) and biaxially oriented polypropylene (BOPP) are compared to a microscopic mean field theory for dielectric breakdown in highly disordered insulating materials [5]. The broader range of measured ramp rates (~0.1 V/s to ~500 V/s) provides a test of the signature curves predicted by approximate and more complete theoretical models.

A first order approximation for how the estimated breakdown field depends on the ramp rate, dV/dt, comes by assuming that the ratio of breakdown fields at two different ramp rates is the same as the ratio the chance of breakdown at the same ramp rates [5]. This predicts a F_{ESD} increasing with increasing rate. A more complex model includes details of the voltage and time increments for the ramp rate. Given changes in either ΔV or Δt only, it should be possible to fit data to the more advanced model using numerical schemes; this will be the topic of future work.

3. EXPERIMENTAL METHODS

We present additional ramp rate testing data on BOPP and PI (Kapton HN™). Samples of the materials to be tested were placed between a metal sample mounting plate and six highly polished copper high voltage electrodes [5]. A spring clamping mechanism was used to apply uniform sample contact pressure of about 0.4 MPa, in compliance with standard methods. For ramp rate tests, voltage was incrementally increased at a constant rate until breakdown occurred, which was evident by the current increasing significantly and continuing to rise linearly above breakdown.

4. RESULTS

Each ramp rate test was compiled into a single graph for each material showing ramp rate versus the breakdown field at that ramp rate. Between three and six tests were done for each ramp rate, and the combination of all tests done at a given ramp rate yields one data point in Figures 1(b) and 1(c). Figure 1(a) adds past ramp rate data taken on the material Kapton E™ (an alternate form of PI). Faster ramp rates yield less information than the slow ramp rates.

5. CONCLUSIONS

Expanding the range of ramp rates and the materials tested has not confirmed the trend set by Kapton E™ tests. Ramp rate has less direct effect on F_{ESD} for Kapton HN™ and BOPP than for Kapton E™; however, ramp rate still physically affects all materials tested. These effects become significant when tests are orders of magnitude faster than real spacecraft charging situations, which is the case when the standard ramp rate of 500 V/s is used.

In addition, to more realistically recreate a spacecraft charging situation, slower ramp rates also yield more accurate and precise data because the step size is smaller. These tests produce data with more physical meaning than the fast tests do, such as pre-arcing [12].

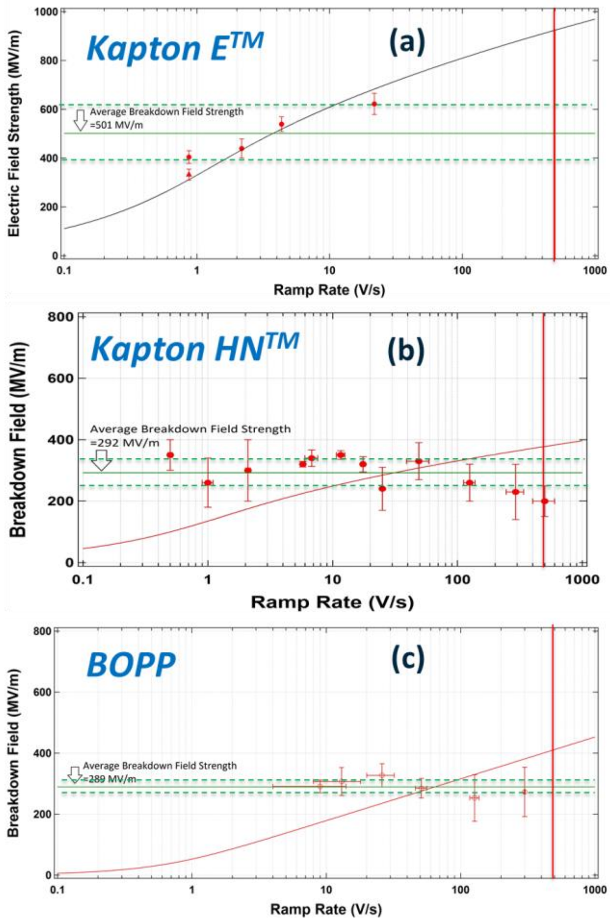

Figure 1. Breakdown field versus ramp rate for: (a) past tests on Kapton E™, (b) tests on Kapton HN™, and (c), new results for BOPP. The red curve is a fit based on Eq. (2). Horizontal lines show the mean F_{ESD} and one standard deviation. The recommend maximum ramp rate of 500 V/s [4] is marked by the vertical red line.

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