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Electrostatic Breakdown Analysis

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URCO Final Report

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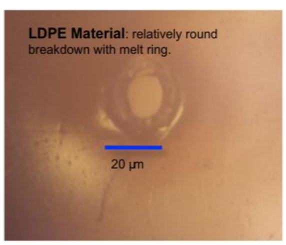
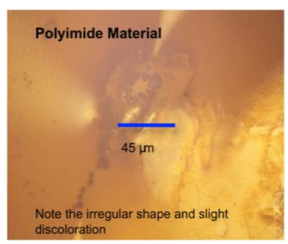
Abstract

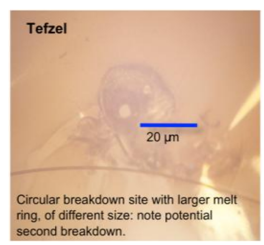
Materials potentially suitable for spacecraft construction were exposed to electrostatic discharge in the USU Materials Physics Group lab, with hopes of identifying samples that possess greater resistance to breakdown. Breakdown shape and size may be important to determining material suitability for spacecraft construction [1]. The discharge damage sites of tested samples were examined, measured and logged into a matrix file for data analysis. Once logged, data was sorted within the matrix and compared graphically to identify trends.

Process

Breakdown samples were analyzed and logged into the matrix based on breakdown size, shape, and noted abnormalities.

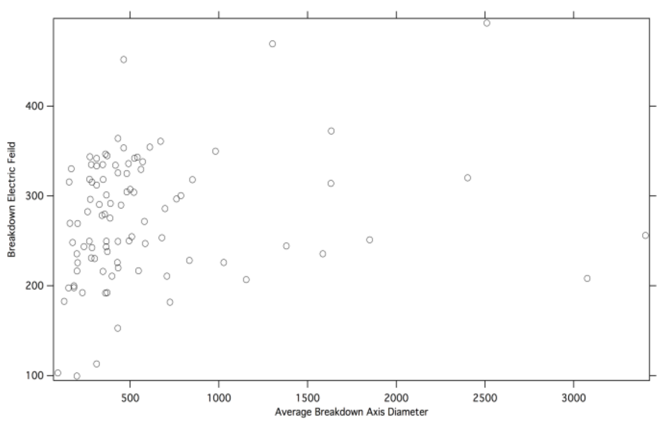






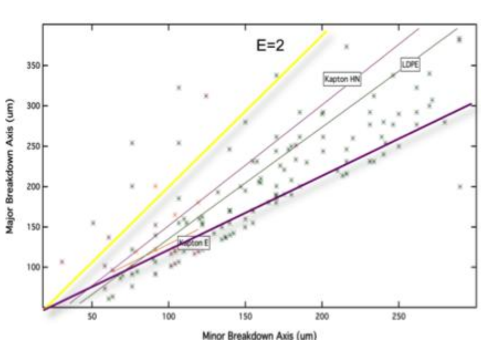
Processed samples were carefully imaged with a ruler under microscope for scaling purposes, then labeled and saved in our Electrostatic Discharge Quality Summary Table. Once saved, images were analyzed using photo-editing software. Proper scaling was determined for each image and major and minor axis measurements were recorded. Last, the average sample thickness was determined by measuring each material at six locations, this was entered into a separate table and averaged; the average for each sample was then loaded into the Electrostatic Breakdown Quality Summary Table. Other information regarding the tests, such as the breakdown electric field strength, temperature, test type, and material type were automatically entered in the matrix. My research focused on looking for correlations in breakdown characteristics of materials and test types. The ESD Quality Summary Table allowed us to search for trends within each group of materials and tests easily. This matrix contains columns for electric field strength at breakdown, material thickness, breakdown voltage, temperature, chamber pressure, time until breakdown, and breakdown site characteristics. Additionally, eccentricity, average breakdown axis length, and relative breakdown area were calculated for each test sample. Eccentricity was calculated by comparing the major and minor axis as a ratio. This allowed us to quantify the uniformity of breakdown shape. Average breakdown diameter was another measurement used to search for trends in the size of breakdown and their material type. The relation of relative breakdown area to applied electric field was used to examine this relationship. Relative area was calculated by multiplying the axis (major x minor). Since samples were rarely circular, a relative areal measurement was used to quickly search for a correlation in breakdown size and applied electric field. The actual values of each areal measurement hold no significant value.

Results



Electric Field and Average Breakdown Diameter
Figure: 1.0

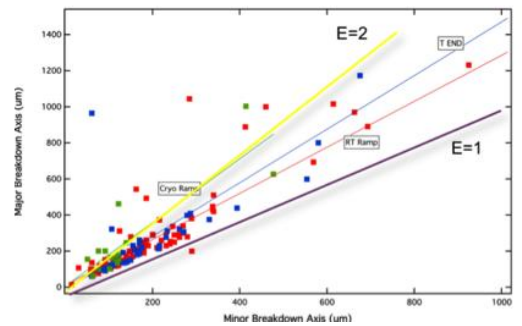
Of interest at the start of the project was the relationship of destroyed material to the applied electric field. Larger areal damage was expected to positively correlate to an increased electric field since higher energies are capable of larger material displacement: $E=mc^2$. Our plotted data (figure 1.0) shows a typical range of electric field values for breakdown, however no correlation was found between this value (e-field) and breakdown axes. Worth noting is the process of determining the areal damage. At the investigation start major and minor axis of displaced material was measured rather than entire damage zone. A more accurate indicator of damaged material resulting from expended energy may be to measure the associated damage melt area surrounding the displaced material (hole), in addition to the actual hole. I believe our graph did not show a correlation as a result of this oversight.



Material Eccentricity Figure 2.0

Breakdown eccentricity of each material flavor was examined graphically by plotting major and minor axis against each other (figure 2.0). This was performed for all material types, as well as the different test types performed on each material. Our work shows that breakdown were elliptical rather than perfectly circular. Eccentricity was measured by creating a ratio between the major and minor axis of each breakdown hole. Our sample group has an average eccentricity of 1.38. The orientation of the ellipse axes was not noted during this investigation. In the future, this would be worth recording since orientation may be important as a system check to determine whether breakdown location is dependant on equipment placement or pre-existing sample deformities.

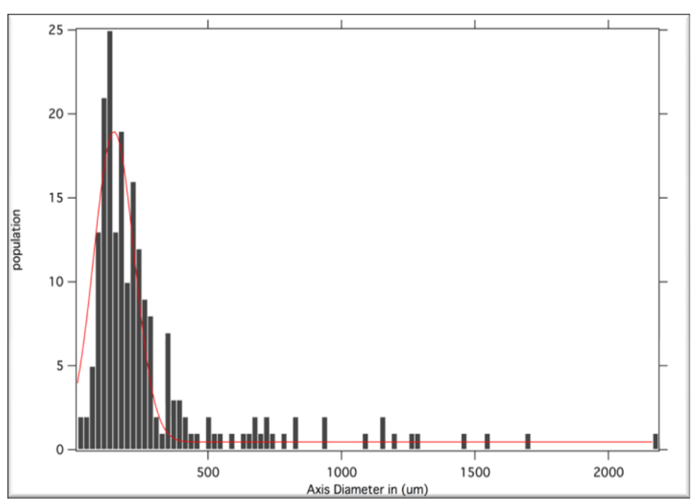
Eccentricity of the different test types was looked at in a similar manner. Types of tests performed on samples included Cryo Ramp (increasing voltage at cold temperatures), RT Ramp (increased voltage at room temperature), and Time Endurance (constant voltage over a prolonged period of time. Cryo Ramping was thought to yield larger areal destruction than the other tests. It was thought that material; which was tested at space temperature (3^o Kelvin), would be denser than at room temperature and more brittle. This change in material property was thought to cause damage to propagate further than at room temperature. A higher eccentricity value or a larger average breakdown value of these test types than other tests would lead us to believe breakdown at space temperatures propagate further, or are larger, than at room temperature. Eccentricity was examined in our major and minor axis graph comparison; Cryo Ramp test types did have a higher eccentricity value of nearly 2. Room temperature tests had an eccentricity of 1.4. When breakdown diameter averages for each group were compared, no relationship between average breakdown diameter and the test performed was noted. Our graph does demonstrate that breakdown eccentricity increased with breakdown size. Samples deviated from an eccentricity of 1 (circular) as their size increased.



Test-Type Eccentricity Figure 3.0

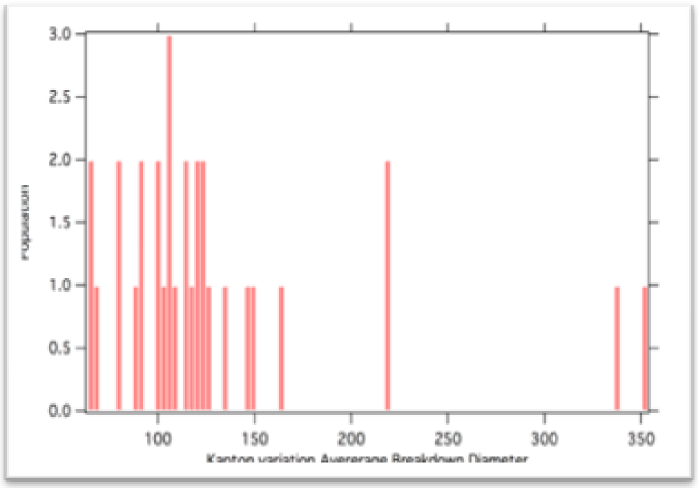
Material thickness and breakdown axis diameter were compared graphically. Thickness of the material could correlate to a greater volume of damaged material with higher applied energies. Separating the thickness of the material from the electric field was not possible and did not lead to any conclusion since the measured electric field value is dependant on the material thickness. The volume of damaged material (damage area x thickness) compared to the applied electric field should show the two are connected positively. This comparison is similar to comparing damage area to electric field, however it would indicate whether material thickness affects the size of damage area. Damage area should be larger in thinner material since more mass is being damaged or removed. Thicker material samples should have smaller damage zones due to the increased mass present.

My comparisons were made using over 200 analyzed samples, the majority of which (78%) were Low Density Polyethylene samples of varying test types. These conclusions primarily apply to this sample type. Kapton E and Kapton HN were also included in our analysis but comprised fewer than 35 test pieces. Populations of each material test type were plotted in a histogram (figure 4.0) to compare breakdown diameter of the entire test group. This showed that there is a normal breakdown diameter. A histogram of multiple Kapton flavors (Figure 5.0) was



Complete Population and Average Breakdown Diameter Figure 4.0.

created to examine whether the predominantly LDPE material falsely represented the rest of our data. Initial trends within Kapton materials indicated that the average breakdown site diameter was in fact 200% +/- 4% smaller. Comparing the population of different materials (figures 4.0 and 5.0) allowed us to locate a potential trend in a materials susceptibility to break down. Our graph shows that this susceptibility is likely due to material type rather than testing differences. Since similar histograms showed no trend when sorted based upon test variations.



Kapton Flavor Samples and Average Breakdown Diameter. Figure 5.0

Error

Systematic error in our measurements was calculated to be 1.4%

Our investigation yielded further questions involving new potential correlations. Changes to the existing process of analysis are necessary to make such comparisons, for example it is thought that the proximity of the breakdown to the discharging electrode may offer information regarding the actual breakdown process. Recording the location of each material failure would also act as a test of our equipment. The breakdown sites may be associated with electrode positioning, or pre-existing material defects.

In conjunction with my inquiry, I created a laboratory manual to standardize measurements. It suggests improvements and additional measurements be made on all future samples including recording the spatial variability of breakdowns and measuring the area directly within photo editing software rather than approximating this using the axis measurements.

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Presentation of Results

As planned in my initial URCO proposal timeline (Table I), I successfully presented my research at the following venues:

- Utah State University Student Showcase, Logan UT; April 11 2014 [2].
- American Physical Society Four Corners Regional Meeting, Orem UT; October 17-18 2014 [3].

My project poster presentation received a best poster award at the APS 4 Corners Meeting in Orem UT in October 2014 [3]. My poster was the only presentation from USU to receive an award. The APS 4 Corners Meeting was beneficial in many respects; it was exposure for our group and it also exposed me to some unique insights and thoughts from distinguished professors in the area on possible correlations.

Personnel Overview

Sam Hansen is a senior undergraduate student majoring in Physics at Utah State University. Sam worked with the Materials Physics Group from Fall 2013 through Fall 2014, under the guidance of graduate student Allen Anderson and faculty mentor J.R. Dennison. During this time Sam became expert at ESD site analysis and classification; after processing hundreds of test samples. In the future, Sam is interested in exploring various other methods through which to mitigate spacecraft and equipment failure due to unwanted charging events and how polymers react to extreme conditions. Sam will graduate with a BS in Physics in May 2015.

Allen Andersen is a graduate student pursuing his Ph.D. in the Physics Department at Utah State University. As a member of the Materials Physics Group his research area is the investigation and modeling of electrostatic discharge phenomena in polymeric and ceramic/glassy highly disordered insulating materials. He provided guidance in experimental design, analysis and interpretation of the data, and helped to relate my results to the current understanding in the field.

J. R. Dennison is a professor in the Physics Department at Utah State University, where he leads the Materials Physics Group. He has worked in the area of electron scattering for his entire career and has focused on the electron transport and electron emission of materials related to spacecraft charging for the last two decades. He provided project oversight and worked directly with me on experimental design, analysis methods, and interpretation of the data.

Table I. Completed URCO Time Line

Objective	Completion
Complete processing of currently available test sample set	March 2014
Present summary of compiled work at USU Student Showcase	April 2014
Creation of instructional manual for ESD acquisition and analysis	May 2014
Complete identification of potential correlations to evaluate	May 2014
Identify additional data required to evaluate potential correlations identified	May 2014
Formulate method to map breakdown location on test samples	May 2014
Acquire additional data as needed	August 2014
Complete data analysis and search for possible correlations	October 2014
Presentation of completed project, and correlations	October 2014

Budget

My project used mainly resources and equipment that the materials physics group already had. There were necessary costs to continue with my project, and measure additional parameters. Extra samples were needed to continue testing and complete the data set. Some test samples could be obtained from cheaper sources, however our vendors were chosen for their product quality control. Material consistency, and uniformity are far greater within this selection set than other alternatives; the quality of these samples allowed us to be far more precise in our research. Some ancillary supplies for the microscope to improve our measurement capabilities are also included.

URCO BUDGET SUMMARY		
EXPENSES:	**Vendor**	**AMOUNT:**
Electrostatic Breakdown Test Samples		
Polypropylene Samples	Goodfellow Metals	$182.00
Sample glue	Tower Hobby	$16.57
Sample cutter backing material	US Cutter	$!95.84
Laboratory Supplies		
ESD Chamber vacuum pump repair	Duniway Stockroom	$309.23
ESD vacuum chamber sample heaters	Omega Engineering	$136.75
ESD vacuum chamber wiring parts	DigiKey Electronics	$48.65
ESD vacuum chamber gaskets	Duniway Stockroom	$181.68
TOTAL EXPENSES:		$ 1070.72
VP for Research URCO Funds		$500
Materials Physics Group Matching Funds (A04395)		$500
TOTAL FUNDING SOURCES		$1000

References

1. Andersen, J.R. Dennison, “Electrostatic Discharge in Solids.” Invited Seminar, Physics Colloquium, Utah State University, Logan, UT, October 8, 2013.

2. Sam Hansen, JR Dennison and Allen Andersen, “Electrostatic Discharge Breakdown Analyses,” *American Physical Society Four Corner Section Meeting,* Utah Valley University, Orem, UT, October 17-18, 2014.

3. Sam Hansen, JR Dennison, and Allen Andersen, “Electrostatic Discharge Breakdown Analyses,” Utah State University Student Showcase, Logan, UT, April 11, 2014.

4. R. D. Leach, and M. B. Alexander, "Failures and Anomalies Attributed to Spacecraft Charging," NASA Reference Publication 1375, N. M. S. F. Center, ed., 1995.

5. Hoffmann, R., J. R. Dennison, *et al*. (2008). "Low-Fluence Electron Yields of Highly Insulating Materials." IEEE Transactions on Plasma Science 36(5 Part 2): 2238-2245.

6. Andersen, A. and J. R. Dennison, 2013, "Charge Transport and Electrical Degradation Research for Power Grid Applications," in *Utah Graduate Student Research Symposium,* Utah State Univ., Logan, UT.

7. Allen Andersen, JR Dennison, Alec M. Sim and Charles Sim, “Electrostatic Discharge and Endurance Time Measurements of Spacecraft Materials: A Defect-Driven Dynamic Model,” submitted to *IEEE Tran. Plasma Science*, 2014, 11 pp.