The Space Congress® Proceedings

2003 (40th) Linking the Past to the Future - A Celebration of Space

Apr 30th, 1:30 PM - 5:00 PM

Paper Session I-C - Comparison of Surface Resistivity and Triboelectric Charge Generation Characteristics of Materials

E. E. Groop
NASA Kennedy Space Center

A. W. Nowicki
Dynacs, Kennedy Space Center

C. I. Calle
NASA Kennedy Space Center

C. R. Buhler
Swales Aerospace, Kennedy Space Center

J. G. Mantovani
Florida Institute of Technology - Melbourne

Comparison of Surface Resistivity and Triboelectric Charge Generation Characteristics of Materials

E.E. Groop[1], A.W. Nowicki[2], C.I. Calle[1], C.R. Buhler[3], J.G. Mantovani[4]
[1] NASA, Kennedy Space Center, FL, USA
[2]Dynacs, Kennedy Space Center, FL, USA
[3]Swales Aerospace, Kennedy Space Center, FL, USA
[4] Florida Institute of Technology, Melbourne, FL, USA

Abstract

Electrostatic discharge can be a significant threat to electronic components, equipment and personnel, especially when working around flammable materials. The development of ways to predict the susceptibility of materials to generate significant charge is important for the safety of these personnel and equipment. The classification of materials as conductors or insulators is based on the surface resistivity of the materials. Though surface resistivity is an important piece of information when choosing electrostatically safe materials, this classification system does not provide any information as to the probability of the materials to generate charge when placed in contact with other materials (triboelectric charging). Without that information, the probability for hazardous electrostatic discharge to occur is not known. In this paper we show that there is no significant correlation between surface resistivity and triboelectric charge generation and emphasize the need for a test method to predict the susceptibility of materials for triboelectric charge generation in order to better evaluate a material's propensity to cause an electrostatic discharge.

Introduction

This paper discusses the importance of both surface resistivity measurements and triboelectric charge generation measurements when choosing materials to be used in sensitive or hazardous environments. Data has been taken to rank materials according to their surface resistivity and these materials were then used in triboelectric charge generation tests to see if there was any correlation between the two measurements. Because of the sensitivity of contact charge generation to the environment in which the materials are used and also to the method of contact between the materials, it is important to develop an in-field test method for triboelectric charge generation.

Importance of Surface Resistivity and Charge Generation Measurements in Preventing and Predicting Electrostatic Discharge

Voltage levels of a few hundred volts to tens of thousands of volts can be generated by every day activity such as walking across a room. An electrostatic discharge caused by charge build-up through these everyday activities can transfer more than enough energy to damage sensitive electronic components or be hazardous in flammable environments. Static dissipative materials allow charge that builds up on the material to leak away slowly unlike insulators where deposited charge on the surface remains stationary. For these reasons static dissipative materials are commonly used in the electronics industry to protect components.

A common misconception is to assume that a static dissipative material protects components and prevents electrostatic discharges. Classifying a material as static dissipative means that the material is capable of bleeding off the charge developed on it but the classification does not reflect the tendency of the material to develop charge in the first place. Dissipative materials are only effective if they are in contact with another material to which they can bleed the charge. If these materials are only touching other insulating materials the dissipative materials will retain the charge that has been developed on them and therefore they will retain the potential to cause an electrostatic discharge. Although it is known to those familiar with the area of electrostatics that surface resistivity and triboelectric charge generation are not related, the electrostatic threats that are present due to triboelectric charge generation are often overlooked or misunderstood when work is done in the field.

The classification of materials as insulating, dissipative, or conductive is shown in Table 1. The surface resistivity values, which are measurements of potential difference per unit length to current flow per unit width, are given for each of the material types.

Table 1: Classification of materials according to surface resistivity.

Classification	Surface Resistivity (Ω/□)
Conductive	$<10^5$
Dissipative	10^5 to 10^{12}
Insulating	$>10^{12}$

The problem that remains with material classification is that although static dissipative materials are capable of leaking charge away, the charge remains on the materials if they are not grounded to an object that the charge can bleed to. Also the ability of a material to conduct or retain surface charge does not reflect that material's ability to develop a large amount of charge in the first place. The triboelectrification of materials (charging of the materials though contact) can cause any kind of material-insulator or conductor-to become charged. This retained charge may be enough in certain situations to generate a potential difference large enough to cause an electrostatic discharge.

Simply put, triboelectrification is the transfer of charge between materials when they come into contact with each other. There are many factors that may affect this charge transfer including environmental factors, physical and chemical characteristics of the materials themselves, and the type of contact that is made between the materials. These factors affect the true contact area between the materials and therefore effect the quantity of charge that is transferred between materials. Some of these factors are listed in Table 2.

Table 2: Factors that affect triboelectric charging of materials.

Factors	Examples
Environment	Humidity Pressure
Material	Work Function Material Transfer Surface Roughness Contamination Surface Deformation
Contact	Force of contact Type of Movement during contact (rubbing or simple contact)

Comparison of Surface Resistivity and Triboelectrification Measurements

Both the surface resistivity and triboelectric experiments were performed under similar environmental conditions. The surface resistivity was measured using two methods in order to provide a means of comparison. The first method consisted of using the Prostat Resistance Measurement System [1] to take the resistance measurements using a concentric ring system. The second system consisted of using the same concentric ring system with a pico-ammeter and a high voltage supply to obtain the resistance values. The resistance values were converted into surface resistivity measurements and the order of magnitude of the resistivity measurements was compared. Over forty resistivity measurements were taken for each material with the measurement taken at different locations on the material's surface. The following chart ranks the materials in order of increasing surface resistivity.

Table 3: Measured surface resistivities for materials used in triboelectric tests. Materials came from lab stock and materials previously tested for electrostatic properties at Kennedy Space Center.

Material	**Surface Resistivity (Ohms/Square)**
Copper	<1
Aluminum	<1
PVF Film	10^{7}
Electronics Bag	10^{10}
AN100	10^{11}
Polyethylene Film	10^{12}
Antistatic Nylon Film	10^{13}
PTFE	$>10^{16}$
Polycarbonate	$>10^{16}$
HDPE	$>10^{16}$

The triboelectric charge developed on one material due to contact with another material was measured by placing the material to be measured in front of an induction probe field meter based on the circuit developed for the Mars Environmental Compatibility Assessment Electrometer [2,3] (Figure 1). The contact is made and the data is taken when the switch, S_1, is open. Because the diameter of the sensing plate is significantly larger than the thickness of the insulating material we can assume a parallel plate capacitor is formed by the insulator and the sensing plate so that charge induced on the material would be equal in magnitude to the charge induced on the sensing plate. The guard ring is also included at the same voltage as the sensing plate in order to reduce fringe effects. The output voltage of the amplifier is proportional to the charge induced per unit area on the sensing plate according to $\frac{Q}{A} = \frac{C_1}{A}\left(\frac{R_1 + R_2}{R_2}\right)V_{out}$, where A is the surface area of the sensing plate. For the instrument used in this case, $\frac{Q}{A} = 16.49 \times V_{out}$ nC/cm^2.

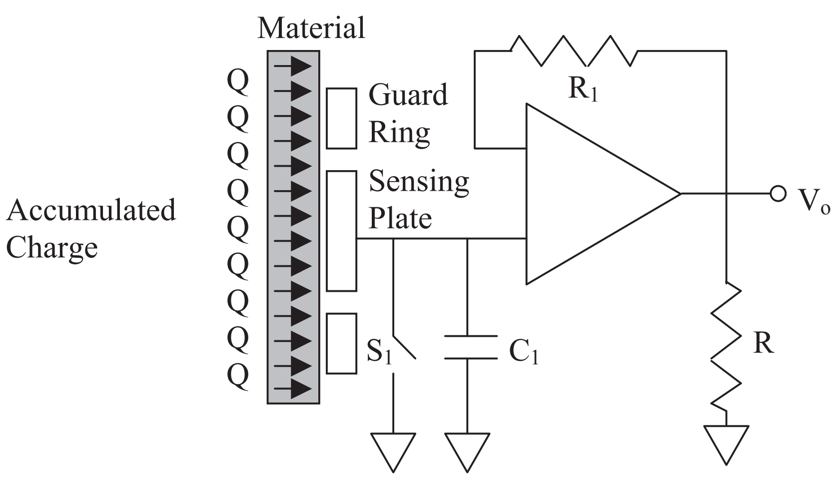

Figure 1: Figure of triboelectric charge test device.

The amount of charge that accumulates on a material is very application specific therefore to compare charge generation tendencies, equally-sized materials were slid against the sensing material under similar conditions (humidity, pressure, duration). The data for both the surface resistivity tests and the triboelectric charging tests were taken under room conditions with the relative humidity between 45 and 50%. The data collected was reasonably consistent for each pair of materials used for sensing and rubbing. At least 20 data points were taken for each pair of ten pairs of materials.

The materials were compared by ordering them according to increasing surface resistivity and by plotting the charge per unit area induced on the sensing plate that developed under contact with each material. The error bars in the following figures represent +/- a standard deviation in order to point out the spread in the charge transfer data for each material. The following representative graphs show how the charge transferred to each material by the others does not correlate with the order of the materials according to surface resistivity.

The sensing materials that are shown in the following graphs come from each end of the surface resistivity range. A conductor, copper, was used as the sensing material in the first graph and an insulator, PTFE, was used as the sensing material in the second graph. If the triboelectric charging of materials were related to the surface resistivities of the contacting materials, there should be some tendency for charge transfer to increase or decrease as the materials move from conductors to dissipative materials to insulators. However, in neither of these graphs do we see these tendencies. Even when comparing only the insulating or dissipative materials there is a wide range of charge transfer tendencies for both the copper and PTFE sensing materials.

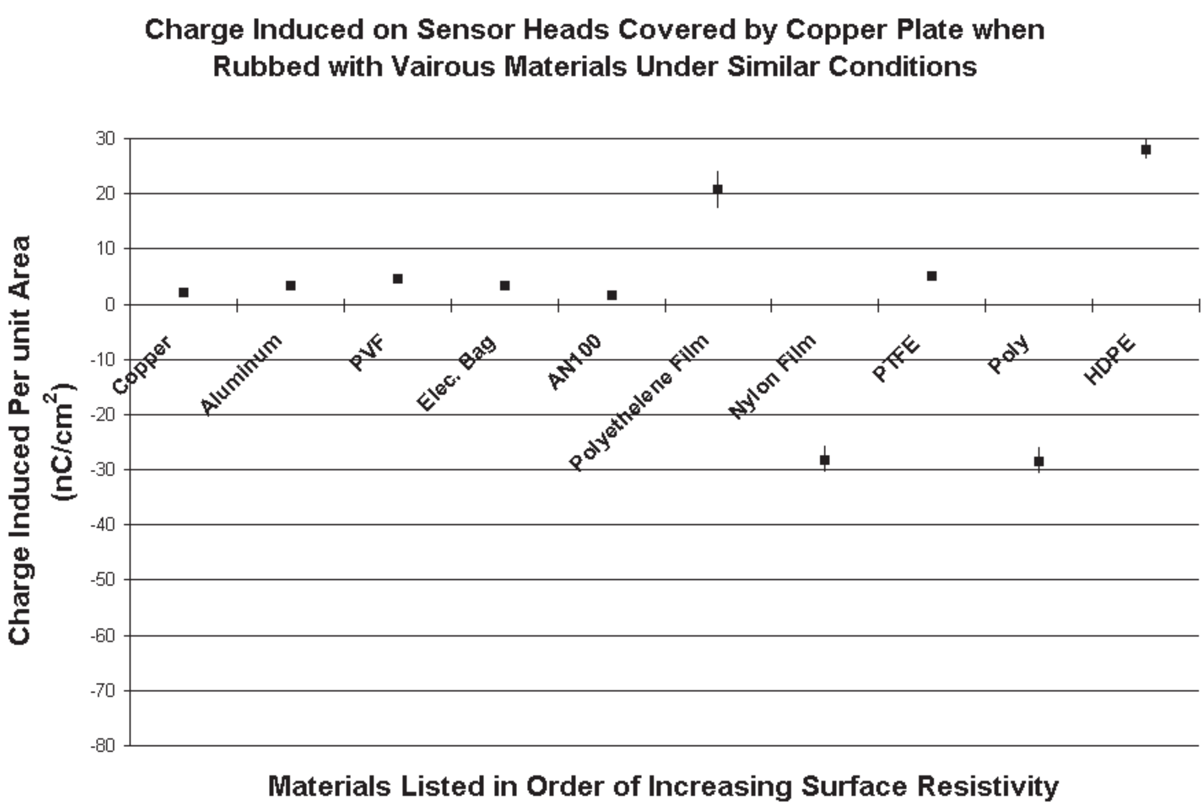

Figure 2: Surface Resistivity and Triboelectric Charge Generation Comparison

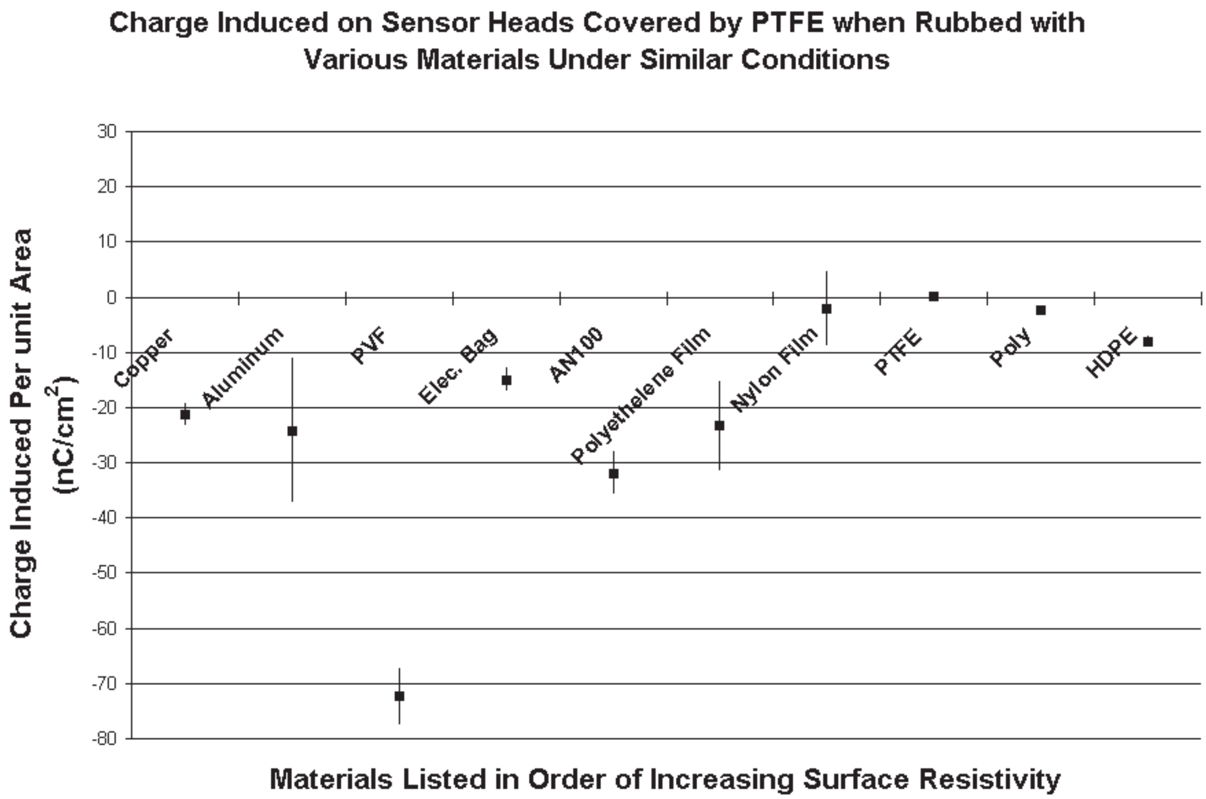

Figure 3: Surface Resistivity and Triboelectric Charge Generation Comparison

As can be seen from Figures 2 and 3 there is no correlation between the tendency of a material to develop charge through triboelectrification and the material's surface resistivity. The data also shows that a significant amount charge can develop on materials through contact, even if the material has very low resistivity depending on what the contacting material is. For example, PTFE exchanged a larger magnitude of charge when contacted with the conductors, copper and aluminum which have low surface resistivities, than when contacted with the highly insulating materials with high surface resistivities. If there is nowhere for the developed charge to drain to, the material can retain a significant amount of charge that could be a threat in hazardous or sensitive environments.

Because surface resistivity data alone does not provide users with the information necessary to make informed decisions on the types of materials that should or should not be used during hazardous activities and in hazardous situations, it is imperative that a charge generation test method be developed to be used in conjunction with surface resistivity tests to better quantify the risks of occurrence of an electrostatic discharge.

Need an In-Field Test Method to Test Triboelectric Charge Generation Tendencies of Materials

Because Triboelectrification is so sensitive to changes in the materials and the environment, it is difficult to develop a standard test method for triboelectric charge generation. There are current methods being used to test materials for the potential of triboelectric charge build up. One method which is used by Kennedy Space Center consists of rubbing the materials with a PTFE pad for a predetermined amount of time and with an electrometer, measuring the charge remaining on the material after contact is broken [4]. Other testing methods have been described in the ESD association advisory for triboelectric charge accumulation testing. These tests use two general methods. The first method consists of charging the material by rolling or rubbing and then placing it into a faraday pail. The second method consists of contacting or rubbing the material across a metal plate and measuring the voltage developed on the plate using an electrostatic field meter [5].

The charge developed on a material is dependent on the other material contacting it along with all the other factors listed in Table 1. For these reasons, it is important to remember that the previously described tests do not necessarily correspond to the way that these materials will be used in applications and therefore the data they provide will not necessarily correspond to the charge that will develop on these materials in the real-world applications. As is stated in the ESD Advisory on Triboelectric Testing, "Relative comparisons of the material's performance that are not based on practical charging situations are likely to yield data dependent upon the test method instead of data dependent upon the materials [5, p.8]." These facts point to a definite need for the development of an in-field test method to measure the triboelectric charge generation tendencies of materials in order that the materials be tested in a configuration as close to its real use set-up as possible.

Conclusion

The probability of occurrence of electrostatic discharges is hard to predict in a laboratory environment because of all the application-specific and environmental factors that affect charge generation on materials when they are used in the field. Many industries rely on the use of static dissipative materials for ESD protection. Although the ability of these materials to bleed off the charge on their surfaces is of great importance in reducing the possibility of electrostatic discharge, there are other characteristics of the materials, like triboelectric charge generation tendencies, that must also be understood and considered. In this paper we showed that the surface resistivity and the triboelectric charge generation tendencies of materials are not related to each other. We discussed the importance of knowing the probability of materials to generate charge and discussed the need for an in-field triboelectric charge measurement device in order to better understand the electrostatic risks posed by the use of different materials.

References

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