SURFACE RESISTIVITY AND TRIBOELECTRICICATION

Triboelectric charge generation by plastic packaging materials is widely believed to be dependent on the surface resistivity of the materials in question. If a material has a low resistivity it is sometimes regarded as having a low propensity for charge generation. This section presents data that contradicts this belief. Surface resistivity and charge generation can not be correlated. However, the belief of a relation of these two parameters persists.

For a material to be "antistatic" it must have a low propensity to generate triboelectric charges. As the following charts show, earlier surface resistivity scales listed an antistatic category. Presently the EIA, ESD Association and Military specifications have dropped any reference to such a relationship. Current standards recognize only three basic resistivities for nonshielding materials:

CONDUCTIVE
DISSIPATIVE
INSULATIVE

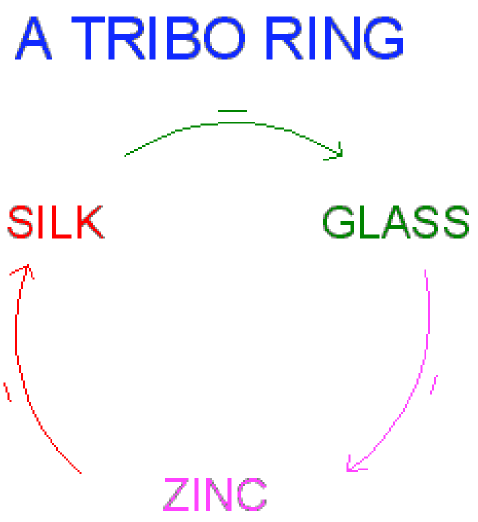
According to Webster's Third New Inter- national Dictionary, Triboelectricity is "a positive or negative charge which is generated by friction." Triboelectricity is from the Greek, Tribein, which means: "to rub." On the other hand, "contact charge" is the positive or negative charge generated by first the contact and then separation of two materials. Typically, in ESD work, these two mechanisms are lumped together in the term triboelectrification or just tribo.

Early electrostatic work placed a great deal of 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. There is little correlation between the series developed by different researchers due to the very complex nature of the triboelectrification process. One such series could be described as below:

Material	Polarity
Quartz	**positive**
Silicone elastomer	
Glass	
polyformaldehyde	
polymethyl methacrylate	
Human hair	
Ethyl cellulose	
Polyamide	
Salt, NaCl	
Melamine	
Wool	
Fur	
Silk	
Aluminum	
Cellulose acetate	
Cotton	
Steel	

Wood
Amber
Copper
Zinc
Gold
Polyester
Polyurethane elastomer
Polystyrene
Natural Rubber
Polyethylene
Polypropylene
Polyvinyl Chloride
Silicon
Polytetrafloroethylene **negative**

The question of whether or not materials at the positive end will always charge positive when rubbed with or contacted by materials lower in the series is not clear. If electron transfer was the only mechanism for charging, at least for certain material combinations, then such a series would certainly exist. However, instead of a uniform series of materials, some "rings" have been shown to exist. The following tribo ring of silk, glass and zinc is but one example of the inconsistencies in tribo series.



Silk charges glass negatively and glass charges zinc negatively, but zinc charges silk negatively. This is the case even though glass is higher than silk and silk is higher than zinc in most tribo series. One may not rely totally on a tribo series to determine the polarity of the charge for the contacting or rubbing together of two materials.

No tribo series may be used to determine the actual quantity of charge resulting from the contacting or rubbing together of two materials. The mechanisms for determining the quantity of charge transfer are extremely complex.

Some of the contributors to the ability or inability of two materials to charge each other are illustrated below. The relative magnitude of the contributions of each is subjective and is not reflected in any academic work. Whether the charging is between two polymers, a metal and a polymer, or other materials, they play vital roles in determining the polarity and quantity of charge.

Surface Physicals
- Tacticity (coefficient of friction)
- Smoothness
- Topology
- Viscoelasticity (conformability)

Material Physicals and Chemicals
- Morphology (amorphous, crystalline)
- Work Function
- Energy Level
- Fermi Level
- Electronegativity (metals)
- Purity
- Polymer Backbone
- Polymer sidegroups
- Physical State (gas, liquid, solid)
- Molecular Mobility
- Temperature

Tribo Series Position

Contact
- Time of Contact
- Area of Contact
- Number of Contacts (repeated contacts)
- Type of Contact
  - rubbing
  - rolling
  - point
  - directional (reversal)

Contamination (surface)
- Humidity/water
- Material transfer
- Surface Reactions
  - oxidation
  - reduction
  - sulfonation
  - flouridation
- Particulate
- Greases/oils etc.

While all of the parameters stated above play roles in the triboelectrification process, no one 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.

It is known that solidified pure rare gases ("ideal" insulators) do not contact charge unless they are doped with electronegative molecules.

Surface resistivity does not play a role in the tribelectrification process. It does however, contribute to the material's ability to bleed off any charge which has been transferred. Materials with surface resistivities in the static dissipative range will not retain static charges accumulated by tribocharging if those materials are grounded.

TEST METHOD

The test equipment set-up used to collect the data presented in this section consisted of an electrostatic voltmeter described by Baumgartner in two of his papers before EOS/ESD Symposiums. It is essentially a charge-plated monitor. The fixture utilizes an insulated aluminum plate viewed by a noncontacting electrostatic voltmeter. The output of the electrostatic voltmeter was connected to a storage oscilloscope. The voltages being measured on the aluminum plate were displayed on the oscilloscope for easy reading. With this test set-up, any ESD material can be evaluated for their tribocharging propensity against many materials or surfaces of interest.

The surfaces against which the materials were tested were attached to the aluminum plate of the electrostatic voltmeter assembly. The charge accumulated on the test surface develops a voltage, which can be effectively viewed by the noncontacting voltmeter with little loading. This voltage is either capacitively coupled to the insulated aluminum plate (in the case of insulative or dissipative materials) or directly coupled in the case of metal surfaces.

The materials being tested were stroked vigorously by hand against the test surfaces for 5 seconds. The materials were then abruptly removed from the test surface at the end of a stroke. The peak voltage was recorded. Four stroke and separate sequences were performed and recorded for each test material and test surface. The results were averaged and reported. The technician performing the tests wore wrist straps, an antistatic lab jacket, and antistatic gloves. At no time during the tests were the gloves allowed to touch the aluminum plate. The test surfaces and materials were neutralized prior to each test to remove any precharges. The test surfaces were cleaned frequently with methyl alcohol (except for the textile surfaces).

The test surfaces used for the data in this section were:
Quartz
Glass
Wool
Silk
Aluminum
Steel
Copper
Ceramic Integrated Circuits
Solder Masked Circuit Board
Polyester
Silicon Wafer (polished)
Natural Rubber
PTFE TEFLON

FPE TEFLON

These surfaces were chosen to represent a wide range of materials, which might give an approximate tribo characterization to the ESD materials under test. Even though these represent the full range of most tribo series, they fall short of providing a true estimate of how a packaging material might react to any other material encountered in electronic manufacturing. These are only benchmarks. To obtain an estimate of the tribo charge-generating propensity for any given ESD packaging material, one must test it against those materials it will encounter in the particular application.

TRIBO CHARACTERIZATIONS

Many tests were run on most presently available ESD packaging materials as well as other materials of interest. The following series of characterizations illustrate that surface resistivity and triboelectrification do not correlate.

For these illustrations the following materials were characterized. They are listed in order of surface resistivities.

MATERIAL	RESISTIVITY Ohms/Square
Copper Mesh	<1
Aluminum Foil	<1
Carbon Loaded Poly Gloves	10^{6}
Carbon Loaded Butyl Gloves	10^{6}
Coated Film	10^{9}
Pink Polyethylene Bubble	10^{9}
Experimental Non-amine Film	10^{9}
Cardboard (used in skin packaging)	10^{10}
Carbon Loaded Foam	10^{11}
Polyethylene Bag (for LCD display)	10^{11}
GLAD Sandwich Bag	10^{11}
Pink Polyethylene Glove	10^{11}
ZIP-LOCK Sandwich Bag	10^{12}
Natural Rubber Sheet	10^{13}
Dry Cleaning Polyethylene Bag	10^{13}

All resistivities and tribocharging were measured at 50% R.H., 72 degrees F. The surface resistivities of the two metals cannot be truly expressed in Ohms/Square. Metals have no true surface resistivity unrelated to their bulk resistivities. The resistances are listed as <1 Ohm only for relative understanding of their position in respect to the other materials tested.

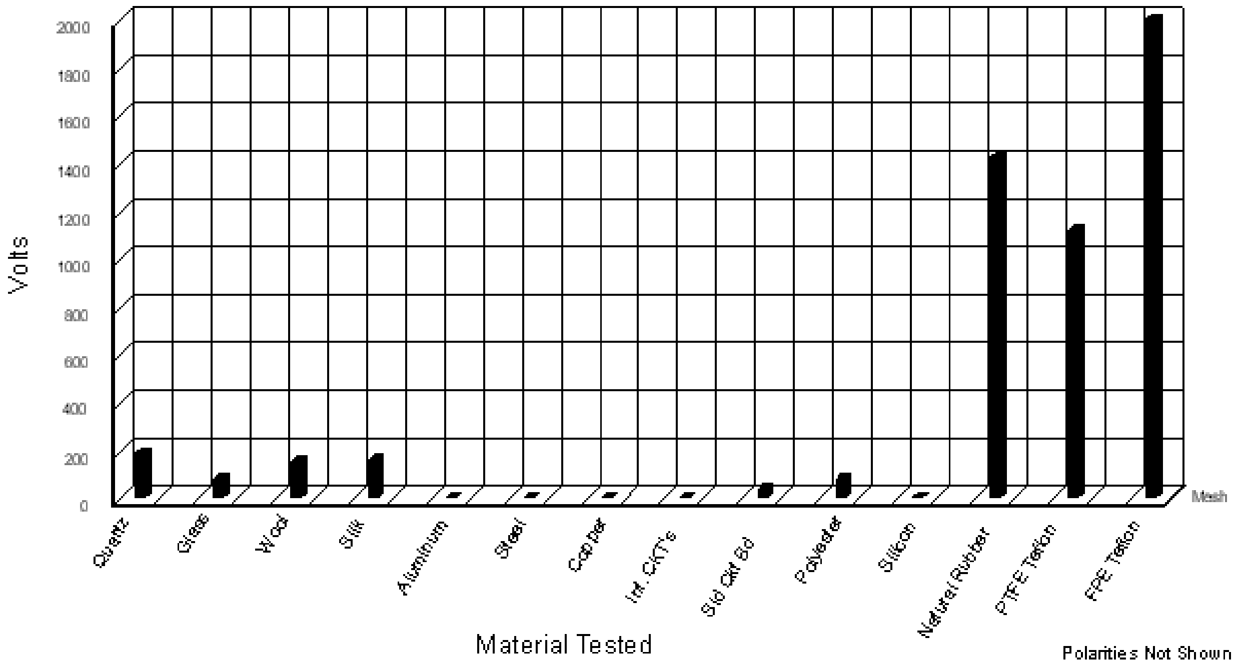


Figure 1. Copper Mesh, < 1 Ohm

With the lowest resistivity of all the materials tested, the copper mesh tribocharged several surfaces to fairly high levels; >2000 volts against FPE TEFLON, 1500 volts against natural rubber, and a few hundred volts against the materials at the positive end of the series.

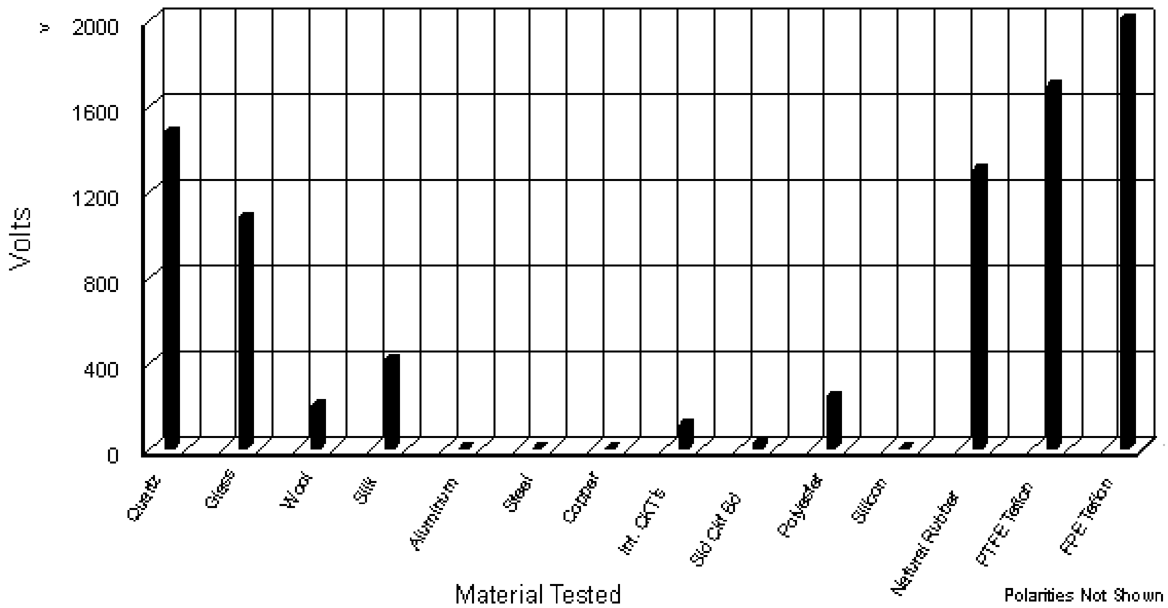


Figure 2. Aluminum Foil, <1 Ohm

Even though its resistivity is extremely low, aluminum foil generates relatively high voltages especially against the opposite ends of the tribo spectrum. This could be due to the oxidation of the surface of the foil. Even against ceramic integrated circuits aluminum generated over 100 volts.

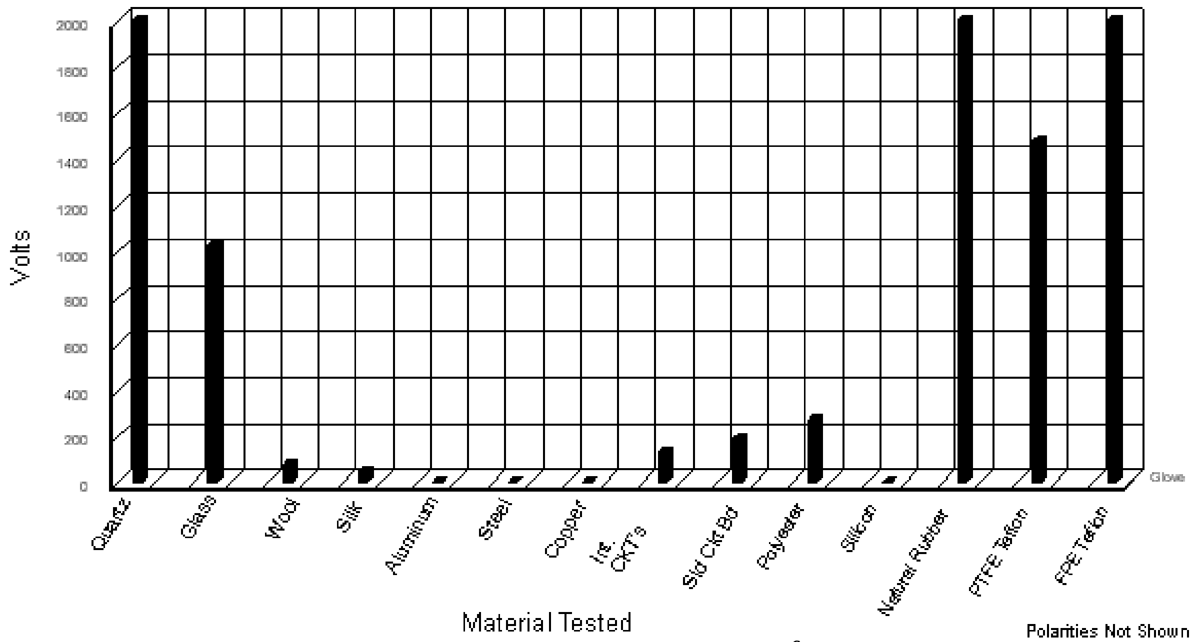


Figure 3. Carbon Loaded Ply Glove, 10^6 Ohms/sq.

While the carbon loading gives the glove a low surface resistivity, it still has a polyethylene backbone structure, which plays a very important part in the triboelectrification process. This type of glove can generate high voltages against both ends of the series. It can also generate several hundred volts against integrated circuits and circuit boards.

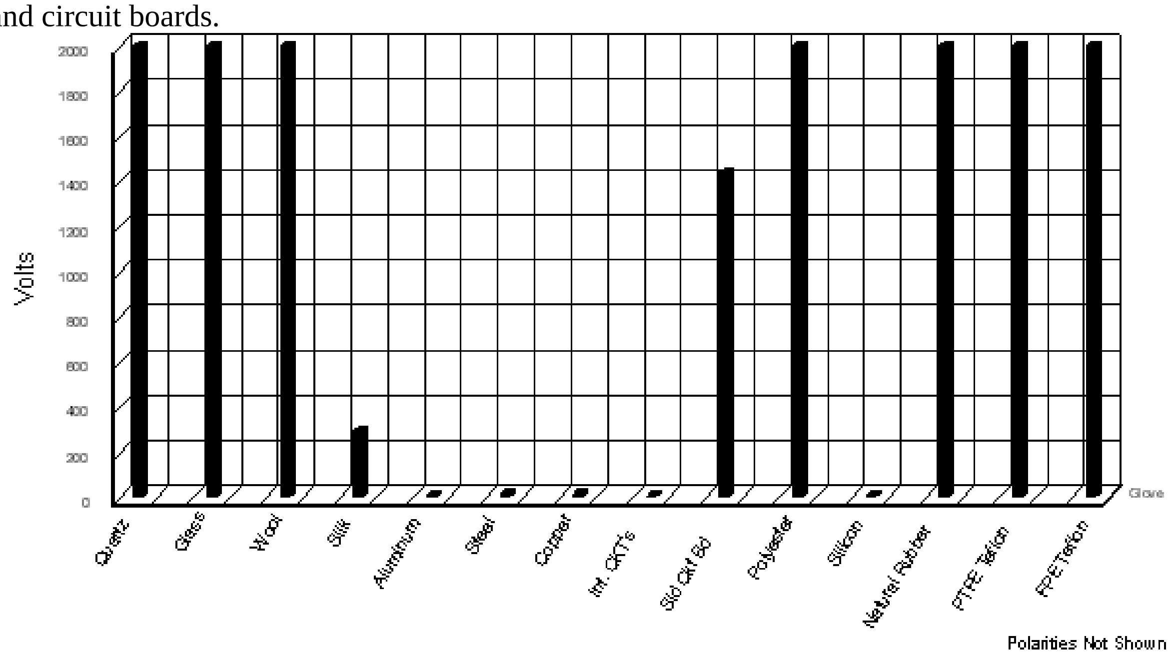


Figure 4. Carbon Loaded Butyl Glove, 10^6 Ohm/sq.

With essentially the same surface resistivity as the carbon loaded poly glove, this one with a butyl rubber backbone generates significantly higher voltages against most of the materials. The voltages against the Circuit board show the dangers of assuming resistivity correlates to tribo charging.

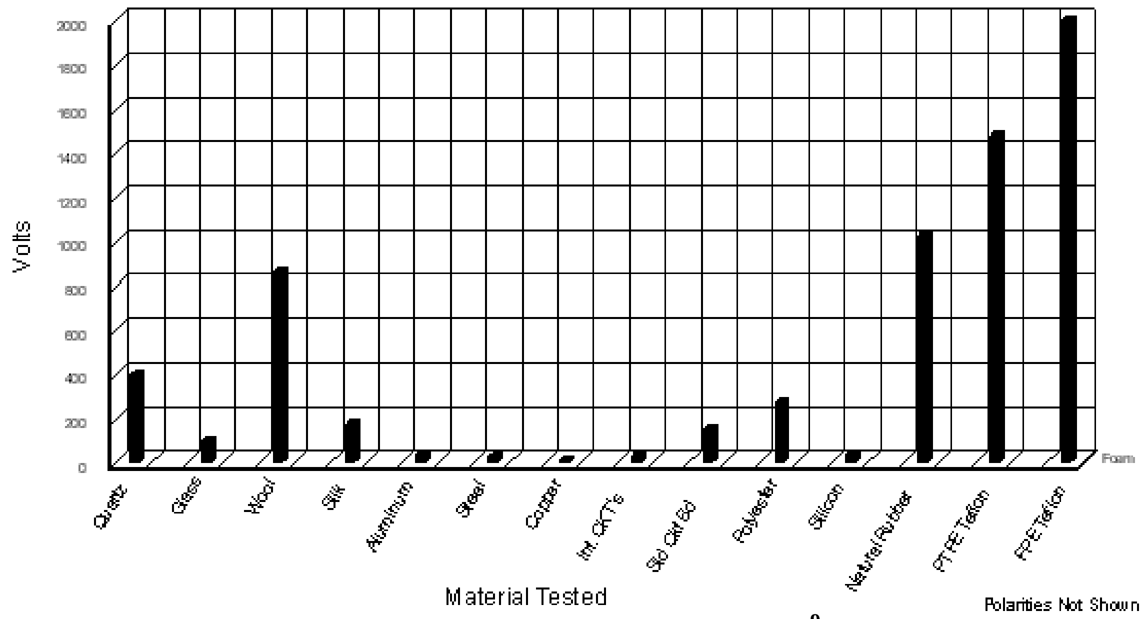


Figure 5. Experimental Non- Amine Film, 10^9 Ohm/sq.

This film does not contain the typical antistatic compounds found in most pink poly films. It shows a very low propensity to tribo charge on most of the series. However, it generates 750 volts against TEFLON.

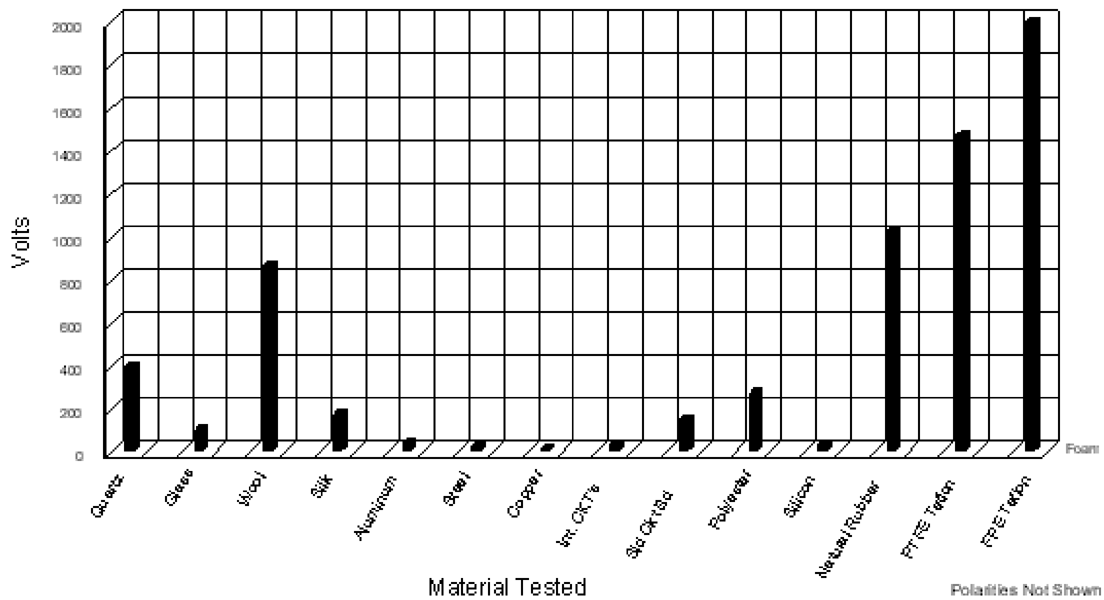


Figure 6. Carbon Loaded Foam, 10^{11} Ohm/sq.

This foam had a high resistivity for a carbon loaded material but showed a lower propensity for charging than the carbon loaded butyl rubber glove which had a lower resistivity. This is probably again related to the polymer backbone structure.

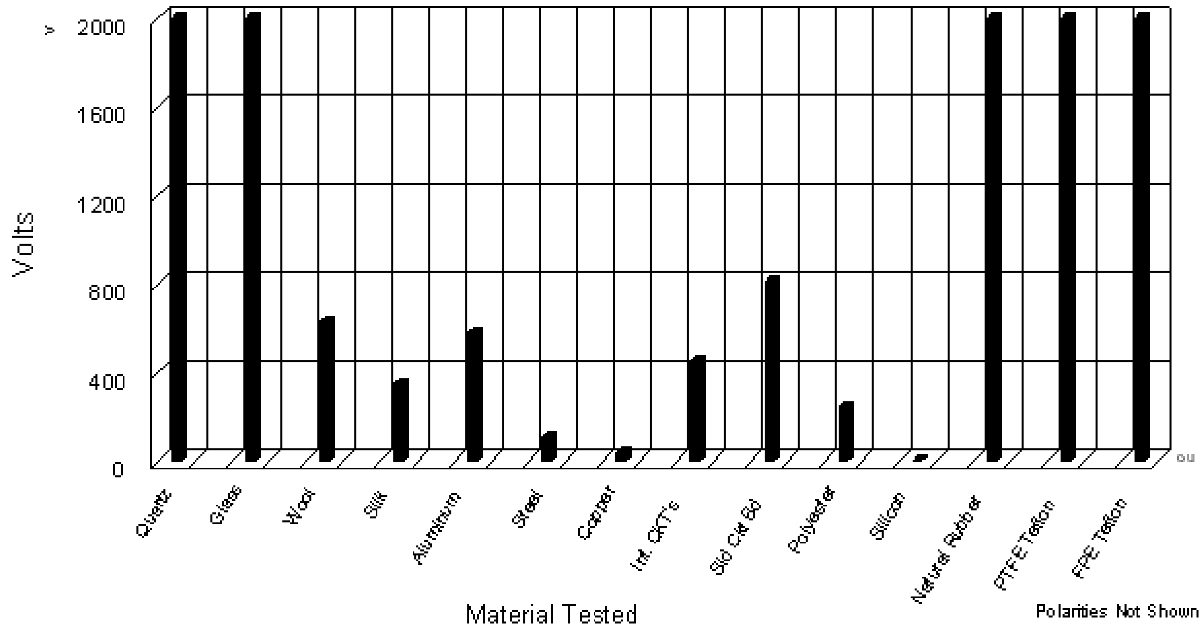


Figure 7. LCD Poly Bag, 10^{11} Ohm/sq.

This bag was received as a package for a Japanese LCD display. It was labeled as "antistatic". However, even though its resistivity was within the industry standards (@ 50% R.H. only), its propensity for charge generation was very high for most surfaces.

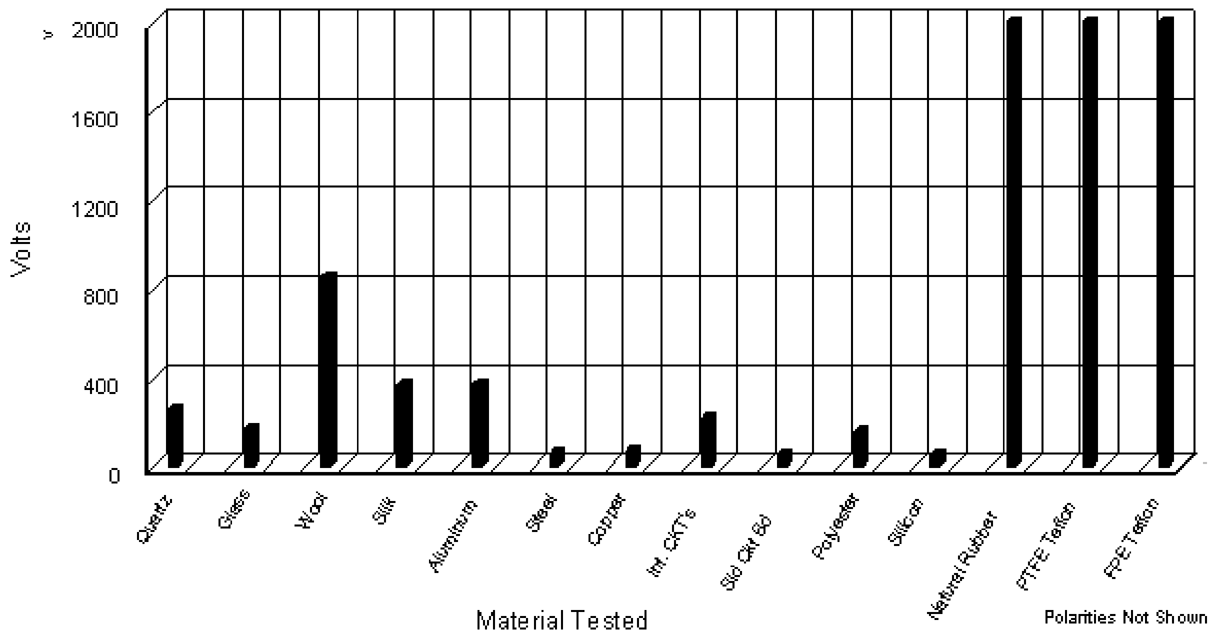


Figure 8. GLAD Sandwich Bag, 10^{11} Ohm/sq.

As a matter of interest, the charging ability of a few common nonanti-static materials were investigated. Unger first noted the low tribo charging propensity of sandwich bags in his paper before EOS-7. As can be seen this material generates high voltages against the rubber and Teflon end of the series. However it does well against quartz, glass, and the circuit board (relatively speaking). It should also be noted that the resistivity was within the limits set by the EIA (@ 50% R.H. only). It is believed that the anti- blocking additive gives the bag antistatic properties at this or higher relative humidities.

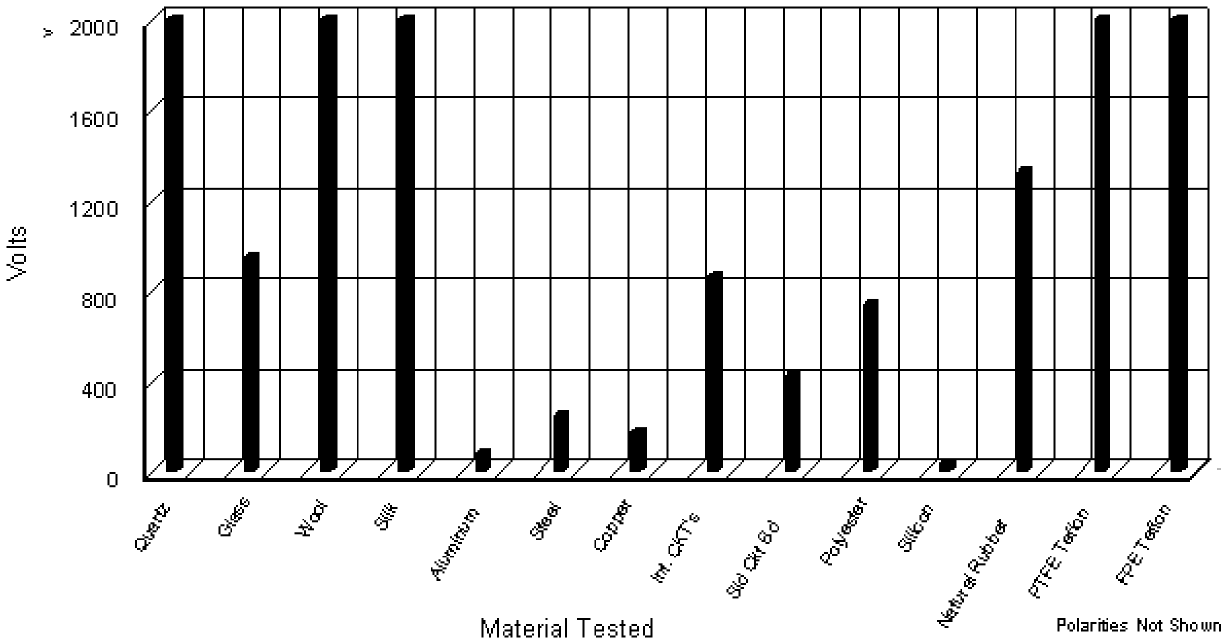


Figure 9. Pink Poly Glove, 10^{11} Ohm/sq.

Even with the surfactant loading this material had a relatively high surface resistivity and high tribo charging propensity.

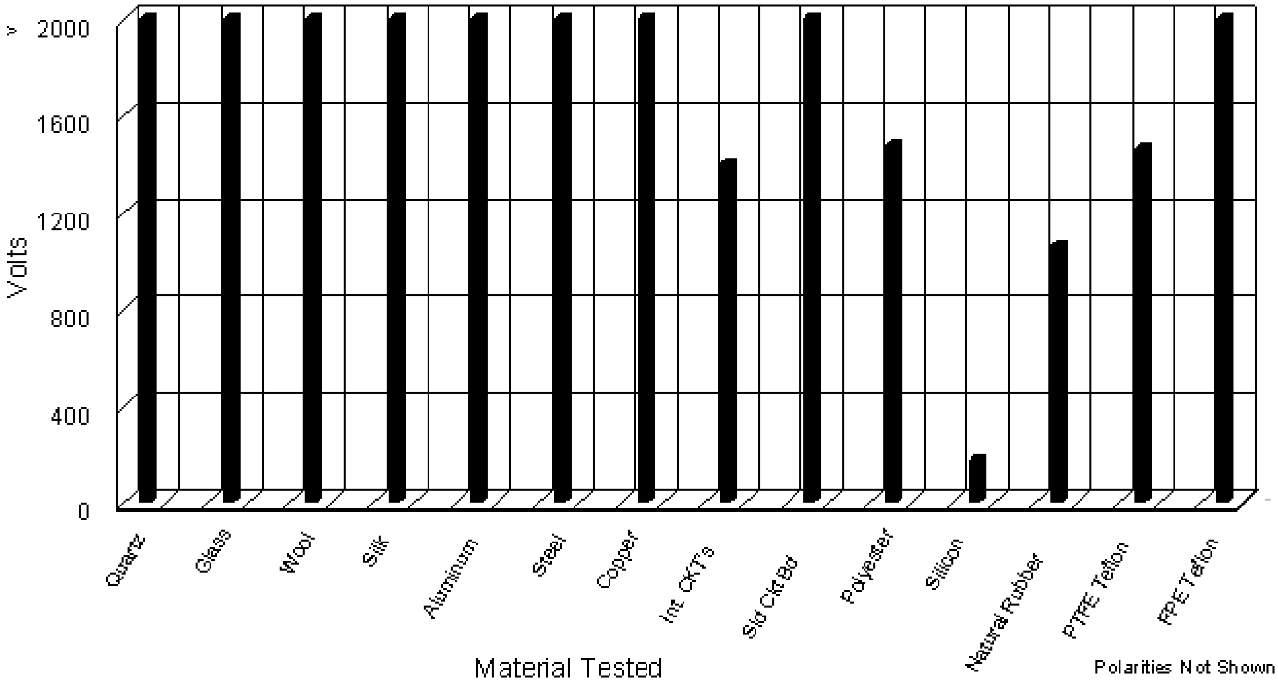


Figure 10. Natural Rubber Sheet, 10^{13} Ohm/sq.

This material acts very much like TEFLON in that it charges all surfaces. The only surface which did not reach readings greater than 1000 volts was the silicon wafer (except against itself). It should be noted that rubber against itself was approximately 900 volts.

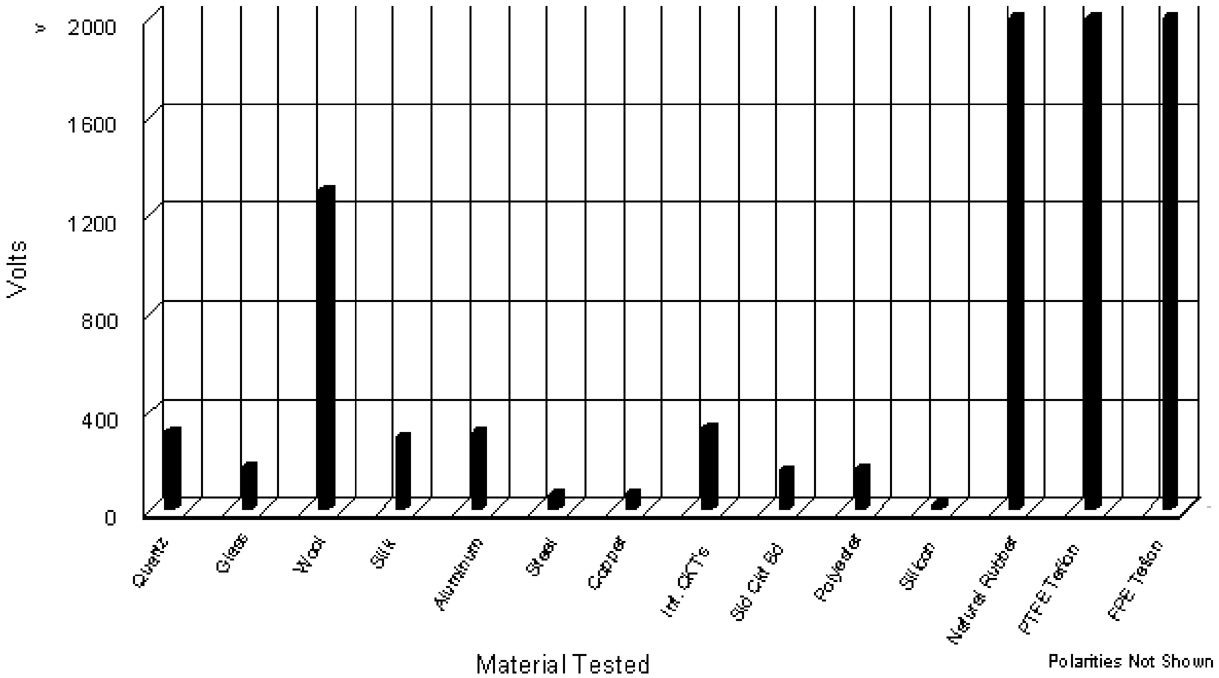


Figure 11. Dry Cleaning Polyethylene Bag, 10^{13} Ohm/sq.

This common nonantistatic material has a high resistivity but low charging propensity against several surfaces.

Tribo Versus Resistivity

The following graphs show surface resistivity and tribo do not correlate.

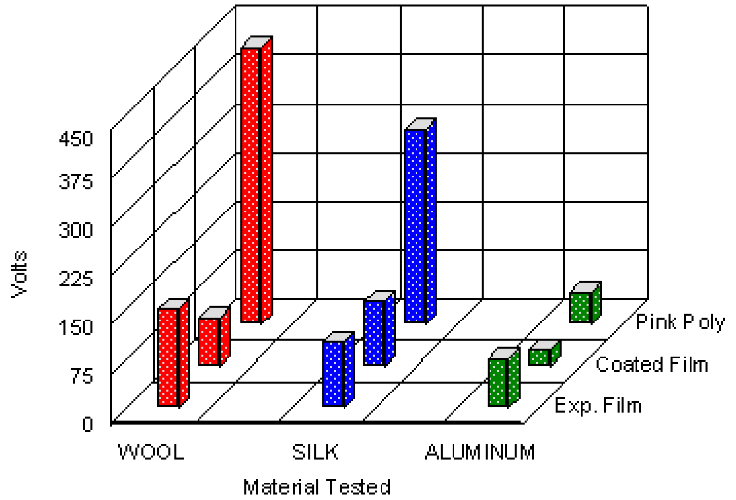


Figure 12 Tribo vs. Materials with the Same Resistivities, 10^9 Ohm/sq.

Even though the materials in Figure 12 have the same surface resistivity, they differ greatly in their tribo charging ability against particular surfaces. Wool, silk, and Aluminum were chosen for this graph for clarity only.

Note: The coated film was not characterized except against the above surfaces.

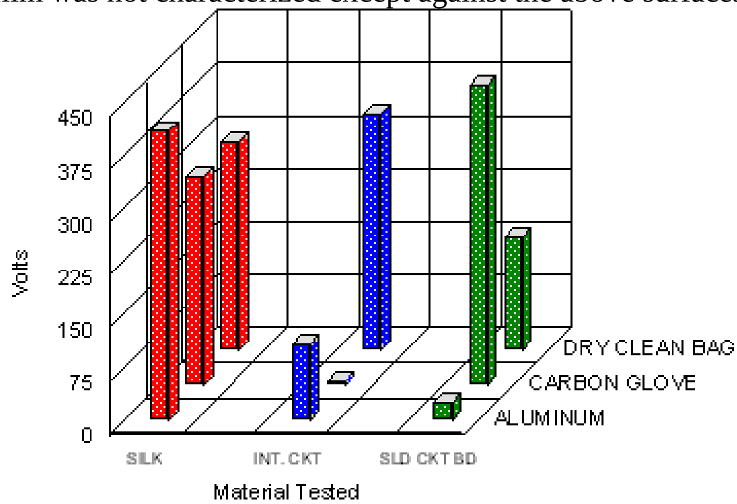


Figure 13. Tribo vs. Materials with Greatly Differing Resistivities, 10^0 - 10^{13} Ohm/sq.

The Dry Cleaning Bag had lower charging propensity against the circuit board than the Carbon Loaded Poly Glove, but higher against the Ceramic Integrated Circuits. Against Silk, all the materials had similar charging. Aluminum shows a higher charging ability against Ceramic Integrated Circuits than the Carbon Loaded Poly Glove.

Assuming a material will not tribo charge because it has a low surface resistivity is very dangerous from an ESD stand point. Resistivity has nothing to do with a material's ability to generate a charge when contacted by or rubbed against another material.

Low surface resistivity, when grounded, will keep charges generated by triboelectrification from remaining for long periods. The lower the surface resistivity the faster a generated charge will dissipate.

Triboelectrification is an extremely complex phenomenon. No single parameter governs the polarity or quantity of charging.

No one tribo series can be constructed.

WHAT DOES THIS MEAN TO THE USER?

The user of anti-static and dissipative materials needs to be very conscious of his application requirements.

All materials tribocharge to a certain extent. The user of these materials must know against what materials the packaging will be used. There is no perfect material. Each benefit in relation to tribo and surface resistivity comes with some drawbacks. To just specify either surface resistivity or triboelectrification propensity will at best lead to problems unforeseen by either or both of these two parameters. As has been shown, the choice of a low surface resistivity packaging material such as carbon loaded plastics may lead to high tribocharges against certain materials. These materials may also slough off carbon particles.

For typical plastic packaging materials the propensity to tribocharge is inversely related to its level of surface contamination. The higher the surface contamination the lower the tribo charging ability. The surface conductivity of the plastic packaging material may be related to the level of contamination only if the contaminant is conductive or hygroscopic. Therefore the specification of low tribo charging propensity and surface resistivity without regard to the packaging application can easily lead to an unacceptable level of contamination from the packaging material.

The manufacturers and suppliers of plastic packaging materials should be asked to supply information on the overall application suitability of their materials, not just the surface resistivity or tribo numbers. The tribocharging ability of any material should be characterized against the materials in the specific application.

Some points of concern which a user of packaging materials must consider are

1. Required Surface Resistivity
2. Required Triboelectrification Propensity
3. Required Static Decay Time
4. Acceptable Contamination or Cleanliness
5. Corrosivity

A total packaging system must be designed, one should not just chose a material which is "anti- static". All the requirements of the application must be taken into account before a material can be chosen. The user and the manufacturer must work together to design an appropriate static dissipative and low tribo generating packaging system.

HIGHLIGHTS OF THIS SECTION

ALL MATERIALS TRIBOCHARGE TRIBOCHARGING TYPICALLY IS INVERSELY RELATED TO SURFACE CONTAMINATION

SURFACE CONDUCTIVITY IS RELATED TO SURFACE CONTAMINATION ONLY IF THE CONTAMINANT IS CONDUCTIVE OR HYGROSCOPIC APPLICATION TESTING MUST BE PERFORMED; DO NOT RELY ON ANALYTICAL DATA

TRIBO CHARACTERIZATION MUST BE DONE ON THE BASIS OF THE MATERIALS IN THE APPLICATION

PACKAGING IS A SYSTEM: ALL FACTORS MUST BE TAKEN INTO ACCOUNT

MANUFACTURERS AND SUPPLIERS OF PACKAGING MATERIALS SHOULD WORK WITH THE END USER TO DESIGN PACKAGING SYSTEMS: IT IS NOT SUFFICIENT TO JUST PICK AN ANTI-STATIC MATERIAL