Overview

Previous studies have illustrated the significant benefits of a comprehensive employee grounding program for effective control of unwanted static charges. Between 1978 and 1982, G. T. Dangelmayer, AT&T, conducted factory studies which documented dramatically different yields between side-by-side identical circuit board assembly lines with only one variable: static dissipative grounding. During a two year long period, in plant studies showed that assembly lines equipped with personnel grounding devices and dissipative table mats produced significantly better yields than lines that did not utilize any grounding procedures. Of greater import, AT&T also noted statistically relevant correlations between compliance with ESD grounding procedures and overall improvements in product quality. Despite 25 years of overwhelming evidence supporting the benefits of personnel grounding, noncompliance with grounding procedures remains a major obstacle to many ESD program managers.

Noncompliance is most prevalent in R & D labs, server rooms, engineering offices, test areas, box assembly, and other scientific spaces where more technically trained people perform daily but non-repetitive tasks. Many facilities install some form of conductive flooring in technical workspaces, assuming incorrectly that a grounded floor will contribute some benefits despite the lack of conductive footwear usage.

This article presents results of a recent investigation. The present study investigated the possible value of conductive flooring without heel strap usage, and whether, under certain conditions, ESD flooring materials might behave like insulative flooring and contribute to walking body voltage generation. During a one month period we measured peak body voltage on individuals wearing several common types of insulative footwear while they walked on six different grounded flooring materials that complied with the recommended resistance range of ANSI/ESD S20.20 tested per test method ESD STM-7.1.

We found no relationship between the resistance to ground measurements and the tribocharging characteristics. We also found that several functional ESD flooring materials demonstrated excessive tribocharging and voltage accumulation on test subjects. The data also suggests that certain types of two layer conductive rubber and ESD carpet tile with conductive thermoplastic backing significantly attenuate walking body voltage even though heel straps were not used. This is most likely attributed to a general triboelectric compatibility of specific flooring compositions with most common shoe sole materials and an extreme lack of compatibility among other triboelectrically active materials. These results also question the validity of choosing conductive flooring solely based on controls, specifications and procedures that will not be duplicated in the actual static sensitive environment.

Background: ESD Flooring Materials, Test Methods And Standards

The ESD Association in Rome NY has generated many useful standards and test methods for evaluating grounding procedures, conductive flooring and personnel grounding devices. The Association’s test methods for evaluating flooring can be traced to Stephen A. Halperin’s, “A Proposed Methodology For Evaluating The Electrostatic Characteristics Of Flooring Materials” presented at the 1990 ESD annual symposium. In his paper, Mr. Halperin proposed measuring both resistance and body voltage characteristics of flooring materials. He concludes that ESD flooring performance is a function of flooring/footwear combinations but not necessarily electrical resistance. ANSI/ESD S20.20 has absorbed those findings by recommending test methods that evaluate ESD flooring by characterizing resistive properties (ESD-STM 7.1-2001), total system resistance (ESD-STM 97.1-1999) and body voltage generation (ESD-STM 97.2-1999). By consulting ESD standards, organizations that use or handle sensitive electronic equipment can intelligently select and install effective ESD flooring solutions without fear of exposing their employees to dangerous low resistance ground connections. But safety isn’t the only concern; excessive electrical resistance can diminish the performance of a grounded floor – footwear system. While a low electrical resistance might expose employees to potentially harmful leakage currents, too much resistance inhibits the decay of static charges, allowing potentially harmful walking body voltages to build up. For this reason ANSI/ESD S20.20 recommends a maximum system “resistance to ground” of 35 X 106 ohms for either a wrist strap system or an ESD flooring footwear system. Armed with lab data derived from ANSI/ESD as well as
AATCC test methods, flooring manufacturers advertise and promote their products using several common performance references: “All (our) flooring meets the minimum recommended requirements of ANSI/ESD S20.20 – tested per ESD S7.1” OR “This flooring will not generate more than 100 volts when tested per ESD STM97.2-1999,” OR “Low KV generation less than 1.5 kilovolts per AATCC Test Method 134-2001.”

A product’s meeting these specifications should be viewed a minimum starting point. Specifications found on product sheets are almost always based on lab measurements on new flooring under carefully controlled conditions. Controlled conditions allow for simple comparisons between various new materials in a non-abusive environment.

Users selecting and specifying materials also need to know what they can expect for performance in a real-world environment that includes traffic, chair caster damage, chemical spills, regular maintenance, and material handling abuse as well as normal product aging. Purchase considerations should always include a contingency plan in the event that the flooring material is used either improperly or in a manner contrary to its intended use.

For example, a floor that generates body voltages below 100 volts when tested per ESD STM-97.2 may generate several thousand volts on a person who forgets to wear heel straps. A dissipative carpet that measures between 1.0 X 106 ohms and 1.0 X 108 ohms may become insulative due to conductive fiber fractures in situations where chair casters constantly roll back and forth over the surface.

These potential scenarios represent serious liabilities to any ESD program and yet they are everyday reality. As previously stated, engineers and lab technicians are least likely to comply with proper ESD personnel grounding policies and yet these individuals test and handle their company’s most important and expensive items. For any of these reasons it may make sense to identify “contingency or adaptive features” during any product selection process. In the case of ESD flooring that logic may constitute identifying ANSI/ESD S20.20 compliant floor systems that also demonstrate low tribocharging characteristics on people wearing standard insulative footwear. Low tribocharging characteristics (triboelectric compatibility) may not entirely prevent the buildup of walking body voltage but a conductive floor with antistatic properties will significantly minimize the liability associated with peak voltages in uncontrolled environments.

**Most ESD Flooring Performs Differently In The Installed Environment**

Some processes used during tile and carpet-manufacturing operations alter the finished flooring surface parameters in one way or another. For example, some processes generate residues. The processing of high vinyl content PVC tiles may create temporary glazes for shine and appearance. These inadvertent surface alterations may temporarily impact the static control performances of new flooring. For example, PVC tiles have a shiny wear layer that disappears after scuffing and heavy use. Eventually the PVC surface must be revitalized through high speed buffing or often, waxing with ESD finishes. The new walking surface may exhibit entirely different tribocharging characteristics from the original factory wear layer.

Rubber flooring may be contaminated with silicone mold release agents that will hinder the product’s dissipative performance until it has been cleaned several times. Data collected in the present study showed a significant improvement in tribocharging characteristic between cleaned rubber flooring and
freshly installed flooring that was still contaminated with factory applied mold releases.

In the case of carpet, antistatic coatings are often incorporated into fibers that reduce static during manufacturing. Although antistatic coatings are not permanent, simple washing will not remove them. However, the coatings disappear over time from traffic and humidity changes. Coatings may remain on the carpet just long enough to prevent walking body voltages over 100 volts during lab testing and initial floor certification. A few months after installation, that same carpet may generate thousands of volts on mobile personnel.

**Accelerated Life Testing Can Reveal Product Weaknesses**

Conductive carpets should always be tested before and after the “chair caster test.” The chair caster test simulates approximately one to two years of task chairs rolling over a carpet's surface in a normal lab or assembly environment. This test had been previously used by carpet mills to evaluate surface wear and it effect on the appearance of yarn systems. The test revealed significant weaknesses in carpet tile designs with PVC backing.

Rolling chair casters destroy or “mash” the carbon fibers in conductive carpeting and can turn a once conductive product into an insulator. Only one conductive carpet design met the recommended requirements of ANSI/ ESD S20.20 after the chair caster test. A properly conducted test should expose floors with conductive yarn systems to at least 100,000 cycles. Our testing demonstrated that a lifetime-time electrical warranty cannot be assumed to confer immunity to caster rolling damage.

Many conductive PVC floors are purchased by buyers that have no intention of applying waxes of any kind. This belief may be shortlived since it costs more to mechanically burnish floor tiles than it does to wax them. Despite the beautiful look of a factory shine, it would be wise to evaluate ESD floor finishes and glazes at the same time as the overall ESD floor tile evaluation. Before buying any resilient floor it is usually a good idea to install a small patch in a high traffic area and monitor performance and appearance. This inexpensive test drive could prevent a costly miscalculation in total cost of ownership and worse – prevent compromised ESD performance due to unanticipated performance problems caused by maintenance and normal use/abuse.

**Test Flooring Based On Real World Conditions**

Will the operation require the use of heel straps or other types of conductive footwear? Many labs and technical environments cannot mandate or monitor compliance with a required use of heel straps. Unfortunately, these environments still require some form of ESD mitigation. Here, it may be prudent to purchase flooring based upon meeting not three but on four electrical testing parameters:

1. Resistance to ground,
2. Total system resistance,
3. Voltage measurement in combination with a person with conductive footwear, and
4. Voltage measurement in combination with person wearing uncontrolled footwear.

Our testing demonstrated that certain materials can meet the first three criteria and perform reasonably well in the fourth test. The decision to address or ignore the fourth criteria is strictly a function of confidence in procedures. A periodic analysis of user heel strap compliance in similar operations usually predicts what can be expected.

**Understanding Charge Generation**

The propensity of contacting materials to generate walking body voltage, or their “triboelectric compatibility” is not determined by measuring the conductive properties of a material. Conductivity is a separate parameter involving a flooring material’s intrinsic ability to discharge stationary and moving conductors. In the case of flooring, conductivity influences charge accumulation only when moving persons interact with the flooring surface while wearing special conductive footwear. In the absence of conductive footwear, the resistance to ground of a floor has little or no impact on static charge accumulation on people. Our tests were conducted to determine the range of expected voltages on people wearing normal footwear.

The generation of static electricity from contact and separation of materials is a well-documented phenomenon. Any time two materials mechanically interact and then separate, there is an exchange of electrons between the two materials. If one or both of the materials are either nonconductive or insulated from ground there is a distinct possibility of charge retention on either or both materials. In the case of people and floors, we know that shoe soles interact with the flooring surface and either strip or deposit electrons during walking. When we detect a negative static charge, that material or in this case person has accumulated an excess of electrons from the floor. A positive charge means that a person has a deficiency of electrons from a similar scenario but, likely involving different material compositions from the first scenario. Certain materials demonstrate strong, repeatable tendencies and always charge to a particular polarity (positive or negative) when they are frictioned by other
materials. This proclivity to charge to a specific polarity is reflected in the “triboelectric series.”

**Test Method And Samples**

Triboelectric compatibility or walking body voltage was determined by measuring and evaluating accumulated static charges on test subjects as they walked across 48” by 48” grounded floor surfaces on access floor (raised flooring) panels. The walking pattern was similar to that described in Figure 1 in ESD STM97.2-1999. All floor surfaces were mounted and grounded per the manufacturer’s installation instructions. Each subject wore a wrist strap connected to an ungrounded floating metal plate that was attached to a calibrated Monroe Model-268 Charge Plate Analyzer. No grounded footwear was used. At the end of each walking session, test subjects were grounded to insure that all sessions began at zero volts. Five types of shoe soles were tested: 2 rubber, 1 leather and 2 synthetic composition soles. All measurements were collected using a recently calibrated analyzer set to “peak voltage” mode. Only peak voltages were collected. All graphs and data reflect kilovolts unless noted otherwise.

**Triboelectric Series And Work Function Theory**

Please note the location of PVC and hard rubber on the triboelectric series. Hard rubber is positioned very close to the center of the chart while PVC is one of the last materials near the bottom. The center of the chart is considered a neutral zone while the two extremes represent materials that charge and accumulate charge more easily and with more material combinations. The most potent material interactions should occur when a material from one extreme is frictioned against a material from the opposite extreme. Additionally, materials that reside in the neutral zone tend to produce the least amount of static electricity when frictioned against other materials at either extreme. Our observations involving rubber and PVC conformed to these predictions.

The tribocharging properties of conductive carpet are not explainable based solely upon positioning in the triboelectric series. All tested carpets were composed of nylon yarn, an insulator and known generator of static electricity. Nylon is an extreme material in the triboelectric series. Conductive carpet’s low charging propensity may be attributable to thousands of conductive filaments on the surface. These filaments are the last points of contact when shoe soles separate from the carpet surface. The poor performance of the PVC carpet tile may be attributed to crushed (no longer part of the upper surface of the carpet) conductive fibers from chair caster abuse.

![Triboelectric Series Diagram](image)

*Note: This chart represents an amalgamation of many different triboelectric series found in various environments.*

**Testing Results**

Test results for rubber and PVC were consistent with the predictability mentioned in the previous paragraphs. Dissipative PVC flooring produced static voltages significantly greater than rubber flooring undergoing the same material interactions. The mean voltage measured on people walking on conductive rubber flooring was .34 kilovolts or 340 volts. The mean voltage measured for the dissipative PVC interaction was 3.13 kilovolts or 3,130 volts. Since the PVC testing yielded a graph that appears bimodal, at least for the shoe sampling used in this testing, the mean voltage should not be used as the comparative statistic in this evaluation. However, the lowest voltage interaction measured on PVC, was between rubber soled shoes and the floor; the mean of those interactions was 2000 volts. Since all means for all rubber floor interactions were below 500 volts there is still a dramatic differential (4:1 minimum and over 10:1 maximum) between the two flooring materials.

All ESD carpet tiles generated lower walking body voltages than dissipative PVC tile. Triboelectric generating properties of the 50cm PVC tiles were significantly impacted by the chair caster abuse test. Damage from chair caster abuse raised the resistance to ground per ESD STM7.1 of the PVC backed carpet tile from acceptable (10$^6$ to 10$^8$) to unacceptable (over 10$^{10}$). There were no measurable consequences from 100,000 cycles of chair caster rolling over the thermoplastic backed conductive carpet tiles.

**Figure 2:** Materials can be ranked in terms of their propensity to lose or gain electrons under friction. This ranking is approximate, and not exact. The ordering can vary with different pairs of materials.
Conclusions

1. The data suggest that a dissipative PVC floor without conductive footwear offers marginal static control advantages and in fact could represent an unnecessary liability.

2. Based on the cross section of shoe soles and conditions, it is unlikely that moving people will generate over 400 volts as a result of interactions with a conductive rubber floor or over 600 volts on a conductive carpet tile with conductive thermo-plastic backing. It is more likely that the walking body voltages will be around the respective mean values of 250 volts and 450 volts.

3. The normal distribution of both rubber and carpet flooring graphs suggests that triboelectric performance may be more predictable for certain flooring materials than other materials. In the case of rubber this may be the result of triboelectric tendencies influenced by material work function (see ESD Association ADV11.2-1995 for further explanation.) Conductive carpet's antistatic tendency may be explained by the principle of "charge backflow." (Also see ADV11.2)

4. The bi-modal nature of graphs of the PVC testing illustrates tremendous voltage variation depending on shoe soles.

5. Any performance evaluation of ESD flooring materials should consider the amount of procedural control and the level of compliance an organization can reasonably expect in their environment. Unless access to and procedures within technical spaces are carefully controlled, conductive rubber flooring or conductive carpet may offer a significantly lower threshold of risk from static charge generation than dissipative PVC. In uncontrolled environments the data suggest viewing flooring materials as preventive/environmental controls that should attenuate static on moving bodies independent of heel strap compliance.

6. A fault tolerant floor grounding system can be achieved by installing ESD flooring materials with a combination of antistatic and conductive properties.

7. These findings present significant implications on the selection criteria of flooring for uncontrolled environments where sophisticated electronics are used for health, safety, security and other mission critical activities.

Further Notes On Test Materials

Flooring types used in tests

A. New ESD carpet tile with PVC backing 50cm X 50cm
B. ESD carpet tile (A) after 100,000 cycle chair caster durability test
C. New ESD carpet tile with conductive thermoplastic backing 24" x 24"
D. ESD carpet tile (B) after 100,000 cycles chair caster test
E. ESD vinyl laminated to access floor panel with conductive adhesive
F. Conductive two layer rubber with black reverse side 24" X 24"

Shoes used for tests

1. Dress leather loafers with synthetic soles
2. Dress laced shoes with thick rubber soles
3. Hiking boots with rubber soles
4. Dress shoes with leather soles
5. Running shoes with plastic soles

About The Author

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