ESD work surfaces: developments and history

Work surfaces have become a primary line of defense against ESD damage.

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This article reviews electrostatic discharge (ESD) developments and the history of ESD workbenches. ESD-grade workbenches are composed of the supporting structure and a specialized laminated work surface that has been designed to dissipate static charges via conduction to ground. These specialized work surfaces have become an essential primary line of defense against ESD damage. The developmental history of work surfaces described in this article parallels the overall growth of the ESD market and technology growth. The history of current workbench materials began in the early 1980s with the introduction of aluminum layers in laminates. Shortly thereafter, high pressure melamine laminates with specific surface conductivity became available. The introduction of new testing requirements covering low humidity conditions (ESD STM 4.11-1999 and program standard ANSI/ESD S20.20-1999) has created the need for laminates that perform at low humidity. Changing standards and application environments continue to spur the development of innovative and higher performance work surface systems.

INTRODUCTION

The process of an item's becoming charged with static electricity is called electrification. This charge can be transferred to or from the item in two ways: conduction or radiation. If this charge is transferred very quickly, the energy in the charge translates from 0 frequency (DC) to frequencies as great as hundreds of megahertz. As such, the energy might now couple to any device susceptible to this entire frequency range. At these frequencies, radiation, as well as conduction, can cause energy coupling. This possibility provides the explanation for ESD damage to devices not directly in, or connected to, the ESD path. ESD protective products are designed to remove static charge by slowly diverting the charge to a ground reference. This diversion keeps the frequency range at or near DC, enabling protection of any device not electrically connected to the ESD item or to any device with DC blocking protection. ESD workbenches are among a host of ESD protective devices. Typically, dissipation via radiation is not utilized for workbench work surface products, but it is utilized extensively in other applications areas such as air ionizing guns. To inhibit electrification and to prevent ESD, the work surface is engineered to have a specific surface conductivity in the range of 10^6 to 10^8 Ω per square point-to-point resistivity. The work surfaces are therefore only partially conductive and retain some insulative properties. As a result, grounding points must be located at specified distances throughout the length of the work surface.

DEVELOPMENT HISTORY

Static electricity was identified as early as 600 B.C. when the Greeks observed unusual behavior when an amber rod and lamb's wool were rubbed together. Much later, protection devices such as the lightning rod were developed by Franklin in the late 1700s. A British scientist, Wilcke, devised the first triboelectric series in 1775. Later, a more in-depth approach was undertaken by Helmholtz and Shaw in the 19th century.[1] Shaw did important work in the areas of charging and discharging of insulators. This area has become very important today as most plastics are insulators and their static electricity characteristics are governed by their basic insulating nature, as well as by their material characteristics.

In today's world, it is hard to imagine life without plastic materials and their use in clothing, floor and wall coverings, and electronic components. These items and more make up the environment in which we manufacture, use, and service electronic devices. Plastics are typically so highly insulating that they cannot conduct charges to ground to dissipate the charge. However, plastics can develop and accumulate

Series 1[2]	Series 2[3]
Wool	Glass
Nylon	Human hair
Silk	Nylon yarn
Viscose	Nylon polymer
Polyethylene	Wool
Cordura-DuPont	Silk
Human skin	Viscose
Fiber glass	Cotton
Acetate	Ramie
Dacron-DuPont	Steel
Chromium	Hard rubber
Orlon-DuPont	Acetate
	Orlon-DuPont Saran-Dow Chemical
	Polyethylene

Table 1. Two typical triboelectric series.

charges. This Characteristic sets the stage for an interesting relationship between the two areas of technology: plastics and microelectronics.

Until the 1950s, electronic devices and components were fairly rugged systems that required little ESD protection. They could absorb a fairly large charge without serious voltage rise. This situation changed radically with the development of the integrated circuit in the early 1960s. These early ICs were soon followed by a large variety of thin film devices and ever denser and smaller ICs. Thin film circuits and ICs are susceptible to ESD damage due to their small physical and electrical mass and their inherent inability to withstand overvoltages as low as 100 V. Reportedly, some newer chips can be damaged by as little as 10 V. Another radical change has also occurred at the same time—the widespread use of synthetic plastics which can sustain static charge buildup of 1000 volts or more. Indeed, such values are now routinely observed on plastic packaging and work surfaces. Coping with static electricity and inhibiting its ability to damage many electronic components now requires constant vigilance by manufacturers of electronic devices and users alike.

Early efforts to prevent the formation of static electricity quickly showed that this approach was impractical. Therefore, controlling, rather than preventing, static charges became the basic goal of industry. Work in the textile field in the 1950s to control the static attraction of large sheets resulted in the development of antistatic agents. Initially, the focus was on retention of humidity and the addition of fairly straightforward highly ionic surface active materials adapted from the petroleum fuels industry. Continued development in antistatic agents has occurred since then, with today's technology relying on various organic salts and long chain fatty and glycolic moieties to achieve results. In particular, quaternary salts of amines and fatty acids have been found to be effective. Antistatic agents, however, are not suitable for long-term protection in today's workbench market because they inherently depend on humidity for function and because they are impermanent liquid surface treatments. Another class of antistatic agents perform their function by acting as surface active agents. Moisture is required for the functioning of both ionic and surface active antistats to support interfacial activity and ionization.

Another materials approach to provide ESD capability is to incorporate conductive fillers into plastic materials. As early as World War II, German U-boats employed conductive carbon filled rubber coverings on their snorkels to elude radar detection. The conductive carbon black modified the electrical characteristics of the rubber sufficiently to make it effective against the then state-of-the-art 500 MHz. The use of conductive fillers was also applied to ESD applications.

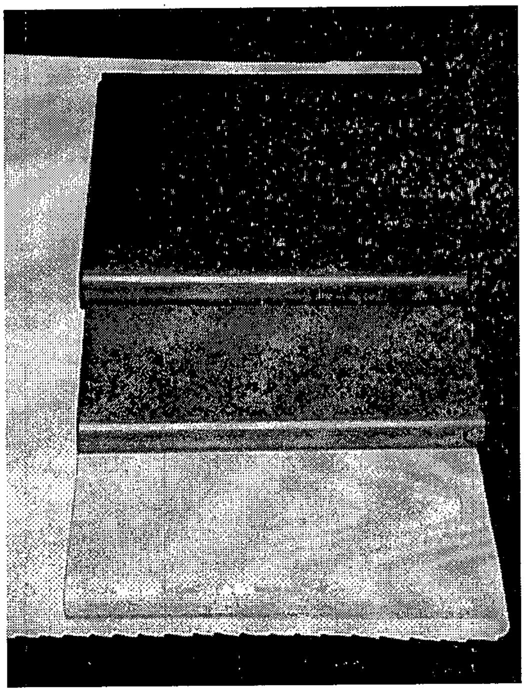

Figure 1. Newly developed homogenous ESD laminates are functional in continuous service at less than 20% RH.

Further efforts to control static electricity were reported in the late 1950s and early 1960s; these efforts involved the use of carbon black in equipment coatings and in PVC phonograph records as a method of modifying electrical conductivity to control static charges.[2, 3] Controlled dissipation to ground as a protective scheme by regulating the materials' resistivity had become a major focus by the mid-1970s. Today, carbon black blended with polymers or as a separate scrim layer is employed in work surfaces and other products.

In developing an ESD work surface, care must be taken to account for material interaction that might produce a desired effect while simultaneously creating other undesirable effects. This necessity is illustrated in recent work using carbon black with ethylene vinyl acetate (EVA). In a study using carbon black and EVA in conjunction with a fatty acid antistatic agent, lowered volume resistivity was observed as expected.[4] However, with carbon black alone, the tribocharging effect was increased greater than tenfold. Clearly, focusing solely on surface conductivity as a measure of ESD capability can lead to overlooking other aspects of ESD performance which are equally or even more important to workbench performance.

As the ESD problem and its significance loomed larger in the 1970s, efforts increased to find workbench protection systems. In the early 1960s at Rockwell and other defense contractors, electrically powered capacitor tables were used to prevent ESD damage to MOS devices.[5] These methods were cumbersome and required constant monitoring. A more reliable and simpler method that was inherently functional for ESD protection was needed. Grounded flooring systems and small temporary work pads were developed during this time. The initial grounded flooring systems, while effective for ESD protection could, under certain conditions, pose a shock hazard. This problem was corrected shortly after introduction. In the 1970s, research focused on efforts to characterize the human body as a source of ESD and the development of component level protection methodologies.[6, 7]

Efforts had been undertaken in the 1960s to produce ESD workbenches by coating standard steel benches with coatings having specific surface conductance. This approach was not satisfactory as the ESD protection was easily compromised. This flow could result in a safety issue or in catastrophic ESD failure if there were any significant variances in thickness, if the coating began to wear thin, or if a break in the coating occurred. (In practice, these "disasters" happened all too frequently.) For non-ESD areas, the standard workbench surface was based on high pressure paper laminates. Workbench manufacturers sought a similar ESD high pressure laminate in order to enter the specialized ESD marketplace. This type of laminate would soon be developed.

ESD workbench laminates began to appear in the early 1980s. Workbench design revolved around the concept of using the infinite electrical mass of ground as a method of lowering transient ESD voltages to levels low enough to prevent damage, while simultaneously draining the charge from the work surface. Early efforts involved adapting conductive carbon black scrim and in using aluminum layers in laminates. The aluminum laminates, developed by Jack Rooklyn, were not practical and were soon abandoned. Rooklyn later developed a post-treatment technique. The ESD laminates based on his technology are commercially available from the Silver Lock Company. Other ESD laminates containing a carbon black scrim layer are available from 3M, Nevamar, and other sources.

When these laminate systems were being developed, the product standards and specifications governing testing specified a fixed 50% RH. This figure was reasonable at the time as humidity levels of 50% RH were being used as a low-cost method of ensuring proper ESD functioning of antistats and other ESD protection systems. However, feedback from the user community pointed out that the current workbench laminates exhibited surface resistivity values outside the standard ESD range when exposed to low humidity (> 35% RH).

Low humidity conditions exist naturally in arid climates and in temperate areas during winter. This phenomenon was not a serious problem with existing electronics during the mid-1980s. By the late 1980s, and through the 1990s, however, changes in electronics, as well as a shift in production locations and environmental working

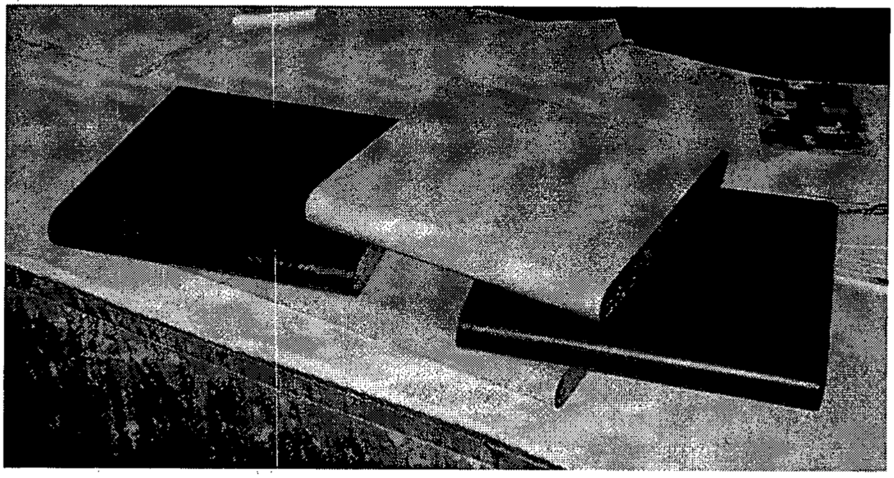

Figure 2. Humidity independent prototype samples are available in various colors and patterns.

conditions occurred. These changes resulted in low humidity operating conditions becoming the norm, not the exception. Many production facilities were located in arid or semi-arid parts of the United States such as Silicon Valley and the New Mexico/Arizona region. From the early 1990s, production facilities have increasingly been located in arid Mexico and northern Canada. Another major factor was a realization that high humidity contributed to corrosion problems and was unsuitable for clean room environments. This problem was addressed by lowering the humidity to 20% RH (Figures 1 and 2). The trend toward adopting 20% RH manufacturing conditions for both regular and clean room environments is now well established and will continue to spread.

In response to these changes, a key ESD standards committee has modified the work surfaces test standard to require reporting of humidity but not compliance with a specific humidity specification. This test is *ESD Association Standard Test Method for the Protection of Electrostatic Discharge Susceptible Items: Work Surfaces—Resistance Measurements*, ESD S4.1-1997. A more recent test standard was issued in 1999 that requires surface resistance performance at 13% RH and other specified humidity conditions. Thus far, no ESD benchtops qualify under this standard, nor under ANSI/ESD S20.20-1999, *ESD Association Standard for the Development of an Electrostatic Discharge Control Program for Protection of Electrical and Electronic Parts, Assemblies and Equipment (Excluding Electrically Initiated Explosive Devices).*

CURRENT DEVELOPMENTS

The newly issued ANSI/ESD S20.20-1999 standard is driving the development of improved laminates for benchtops that can be certified under this standard. Developments are under way at many suppliers with product introductions anticipated in late 2000 to early 2001. The Industry's development activities are focusing on:

- Broadening the spectrum of testing beyond point-to-point surface conductance
- Producing a laminate whose surface conductivity is not effected by humidity
- Retention of performance at continuous low humidity service conditions
- Producing a work surface complying with ANSI/ESD S20.20-1999,
- Developing laminates that can fully comply with clean room standards and requirements.

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Note: References 4, 5, 8, and 9 are representative of a large body of similar work performed during the same time period.

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