CONDUCTIVE THERMOPLASTIC COMPOSITES FOR ESD CONTROL

Introduction

Industry awareness for the need to control ESD (electrostatic discharge) has increased dramatically during the past few years. This need not only exists in the electronics industry, but also in the business machine, automotive and medical industries as well. Electrically conductive plastics are one of the more common media for providing ESD control. These conductive plastic composites are comprised of an electrically insulating plastic into which an electrically conductive filler or reinforcing agent is compounded. Electrical conductivity is achieved via a conductive network of particles or fibers. These composites offer protection in an ESD environment by distributing the charge along the surface and quickly dissipating it into the air.

Additives

There are numerous additives that can be compounded into a thermoplastic matrix to achieve conductivity. These additives can be categorized into two groups — reinforcements and fillers. The *Reinforcing modifiers* are fibrous materials that are either already conductive, or have been surface treated (generally with plated metal) to achieve conductivity. Reinforcements will also increase the strength properties of the base resin into which they are compounded. In addition, these reinforcements can be compounded with sizing systems which chemically bond the fibers to the resin matrix. This permits these additives to be wet-out by the resin and also allows for greater transfer of stress to the fibers, enhancing part performance. *Fillers* are smaller particulate materials with aspect ratios that are well below the critical level needed for reinforcement. Fillers will always reduce the strength properties of the base resin into which they are compounded.

Reinforcements

Carbon fibers are available in two varieties, PAN (polyacrylonitrile) and milled pitch. As their name implies, both of these fibers start from a substance which is furnace graphitized to form a new, higher strength, modulus material. PAN fibers are available in both continuous strand and chopped strand, while the petroleum pitch based fiber is only manufactured in a milled form. Polymers reinforced with PAN fibers are much more electrically conductive, and of higher strength, than their pitch fortified counterparts. This is due in part to the higher aspect ratio of the PAN fibers. PAN carbon fiber reinforced composites are available in any resin system and are among the highest strength thermoplastic materials available. For static dissipation, a 10 - 15 weight % carbon fiber loading is generally sufficient. In the past, pitch carbon fibers were less expensive than PAN fibers, and even though they had to be used at higher loadings to achieve equal conductivity (generally 25 - 30 weight %), there was an economic incentive to use them. This is no longer true, as recent pitch carbon fiber price increases have driven the cost of these compounds well above PAN carbon fiber compounds offering equivalent electrical conductivity. Nickel plated PAN carbon fibers are a more recent entry into the market. The thin nickel sheath that is plated on to each fiber further increases the conductivity. Nickel plating does interfere with bonding of the PAN fiber to the resin matrix. Therefore, these composites are not as strong as the unplated PAN fiber reinforced analogs.

Aluminum fibers and aluminized glass fibers can also be used as conductive reinforcing agents. The conductive coating on the glass fiber is only 0.0001" - 0.0003" thick, providing a very small volume of conductive material, since the underlying glass fiber is an electrical insulator.

Stainless steel fibers are one of the newest entries into the conductive additives field. These materials are fine diameter fibers that possess a high surface area to volume ratio. Accordingly, they can be used to achieve conductivity at low loading levels (3-5 volume %, 6-8 weight %), an important consideration because these fibers are quite expensive. The low fiber loadings also minimize machine wear and changes in impact strength, mold shrinkage, and colorability of the base polymer.

Fillers

Conductive carbon blacks are by far the most common fillers used in static dissipative composites. The carbon blacks used are of special grades that are characterized by small particle size, high graphitic structure, high surface porosity and low volatiles content. These irregularly shaped particles, which are composed of partially graphitized nodules fused into grape-like aggregates, provide a favorable geometry for the formation of conductive pathways. The carbon black powders are most commonly used in polyolefins, but are also finding increased acceptance in nylon, polyurethane and polycarbonate based compounds. Typically 5-20% volume loadings of a carbon black are required to provide static dissipation.

Metal powders have also been used to achieve conductivity in various plastics. Unlike carbon powder, these additives are more spherical in shape and have low surface areas. Higher loadings are required (35-40 volume %) and therefore mechanical properties are severely compromised.

Aluminum flakes are yet another filler used in manufacturing conductive composites. These flakes are produced by spraying a molten aluminum alloy onto a quenching device. The resultant melt-spun particles rapidly solidify to produce high aspect ratio aluminum flakes and prevent the formation of a non-conductive oxidized surface. Aluminum flake filled composites are most often evaluated in EMI/RFI shielding applications. However, a 30% weight loading in nylons, polycarbonate, PBT polyester, and polyolefins will provide an effective statically dissipative composite.

Ethoxylated fatty amines are typically used as antistatic additives in certain resin systems. These additives are hygroscopic in nature and depend on the formation of a thin layer of water on the part surface to achieve conductivity. They are also dependent on ambient moisture and perform inefficiently and inconsistently at levels less than 20% relative humidity.

A relative cost ($/lb.) ranking of the most commonly used conductive thermoplastic composites would be as follows (from least to most expensive):

anti-static ethoxylated, fatty amines,
static dissipative carbon powder,
static dissipative aluminum flakes,
static dissipative PAN carbon fibers,
static dissipative pitch carbon fibers,
static dissipative stainless steel fibers,
static dissipative nickel coated PAN carbon fiber.

Resistivity Ranges

Industry recognized resistivity ranges for ESD control materials are defined as follows:

	Surface Resistivity Range
Static conductive/static dissipative	10^2 - 10^6 ohms/sq.
anti-static	10^9 - 10^{13}ohms/sq.

Statically Dissipative (10^2 - 10^6 ohms/sq.) The statically dissipative materials offer the best cost/performance ratio of any of the electrically conductive plastics. These materials can protect sensitive components from high ESD charges (4,000 - 15,000 volts) by quickly dissipating the induced charge to the surrounding air. They are available in a wide range of base polymers including polyethylene, polypropylene, nylon, polycarbonate and the more exotic melt-processable fluoropolymers.

The statically dissipative carbon black filled polyolefin composites are used quite extensively in electronics packaging and handling applications. The polypropylene based compounds, providing improved mechanical and higher temperature performance when compared to polyethylene, are preferred for injection molding and profile extrusion applications. Static dissipative polyethylene based compounds are chosen for vacuum forming and blow molding applications due to their excellent processability. Both polyethylene and polypropylene unreinforced grades are used in static dissipative tote bins, storage boxes, anesthesia valves, PCB guides, and floor and chair mats. (See Figure 1 and Figure 2).

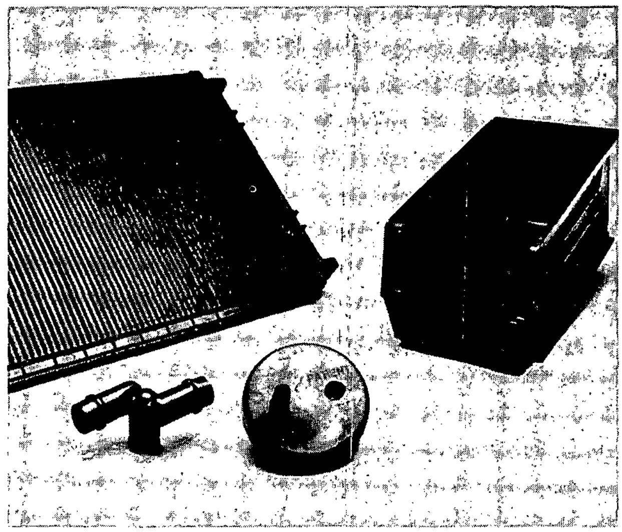

Figure 1. Carbon Powder Filled Polypropylene. a) Tote bin; b) PCB [printed circuit board] rack; c) medical anesthesia valve; d) medical blood cannister lid.

The unreinforced grades offer excellent elongation and impact characteristics. The polyolefins can also be modified with mineral or glass fiber reinforcements. These reinforced grades are finding use in areas such as hanging tote bins, PCB racks and electronic component trays where better creep resistance and dimensional stability are needed.

Carbon powder filled nylon 6/6, polycarbonate and polyurethane static dissipative grades are also commercially available (see Figure 3). The nylon 6/6 based composites offer the excellent strength, stiffness, chemical resistance and short-term high temperature resistance associated with this polymer. Glass fiber reinforced grades provide increased strength and stiffness over unreinforced ones. Static dissipative nylon applications include IC chip holders, conveyor roller bearings, gears, chemical pump diffuser plates, tape drive cartridge hubs, tubing and hoses, and textile cones.

Polyurethane static dissipative grades retain the resiliency, abrasion resistance and high impact strength of the base resin. Paper tractor belts and rollers are two examples where ESD can be eliminated with this material.

Grades of static dissipative polycarbonate retain the excellent "mold-to-size" ability and inherent toughness that is characteristic of this amorphous polymer. Applications include instrument and calculator housings, PCB drawers and telephone recording spools.

The list of static dissipative materials is quite extensive since a low level of carbon fiber (generally 10-15 weight % depending on the resin) can be used in most thermoplastic polymers to achieve composites in the 10^2-10^6 ohms/sq. resistivity range. The carbon fiber can be compounded singly or in combination with different levels of fiberglass to provide an almost unlimited

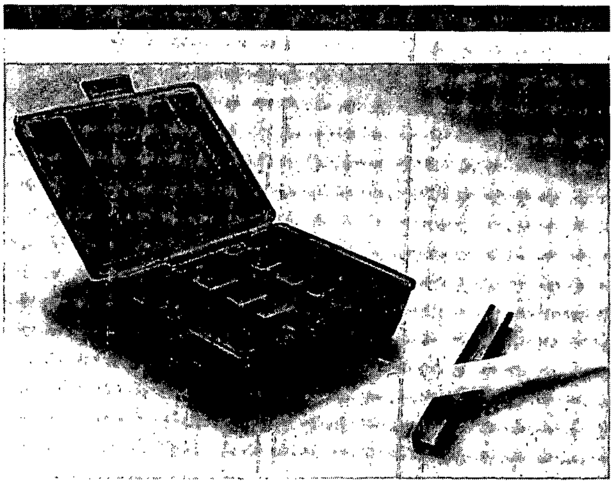

Figure 2. Carbon Powder and Anti-Static Polyethylene. a) Blow molded case for storing computer printer components; b) linear chip magazine using co-extruded anti-static and statically conductive grades; c) anti-static linear chip magazine.

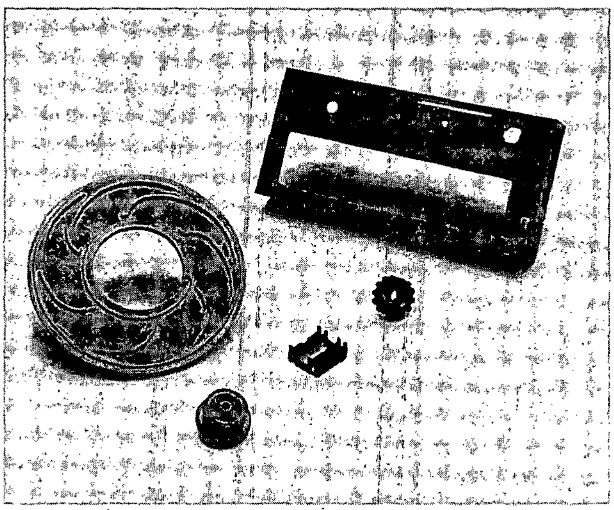

Figure 3. Carbon Powder Filled Engineering Resins. a) Business machine timer pulley, glass reinforced nylon 6/6; b) business machine roller, polyurethane; c) instrument housing polycarbonate; d) chemical pump diffuser plate, glass reinforced nylon 6/6; e) I.C. chip carrier, nylon 6/6.

variety of thermoplastic composites. Because the carbon fiber levels are relatively low, these materials are often cost effective in applications where higher strength and stiffness are required. The low level also allows for some colors other than black. Carbon fiber composites are finding increasing acceptance in business machines where design engineers are able to take advantage of its mechanical and static dissipating properties in structural components. Examples are shown in Figures 4 and 5.

More exotic static dissipative compounds are based on the melt processable fluoropolymers. Both carbon powder and carbon fiber grades of ETFE (ethylenetetrafluoroethylene) and PFA (perfluoroalkoxy modified tetrafluoroethylene) are used in areas where high temperature and/or harsh chemical environments rule out the use of other polymers. Examples include silicon wafer boats that are exposed to chemical cleaning baths and elevated temperature chemical tubing.

Antistatic (10^9 - 10^{13} ohms/sq.) Antistatic plastics will protect moderately sensitive electrical components from low voltages (up to 1,000 volts). They do not offer protection at high potentials due to their higher resistivities. Any thermoplastic composite can be made antistatic by utilizing one of a variety of topical antistats that are being produced. These materials are quaternary ammonium salts of fatty acids and are supplied as dilute solutions in water or alcohol. The topicals provide immediate antistatic protection. However, they lack permanence and can be removed by abrasion, solvents, or physical handling.

Another method of obtaining antistatic protection is through the use of a resin containing precompounded additives. This approach provides a greater degree of permanence of antistatic properties. When a part is washed, the additives will regenerate themselves because of their tendency to migrate to the surface. Regeneration after a solvent wash takes approximately 5 days.

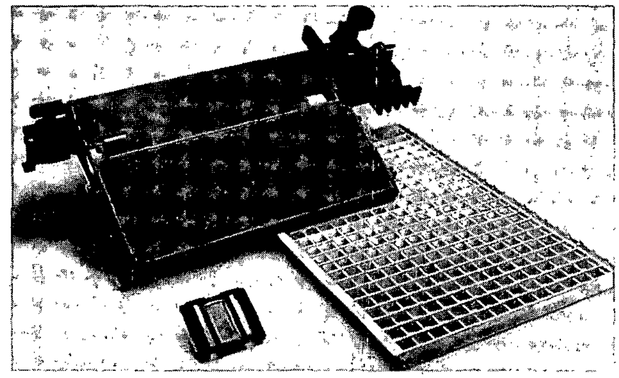

Figure 4. Static Dissipating Pan Carbon Fiber Applications. a) Plotter chassis for a computerized drafting machine, a 10% carbon fiber + 10% glass fiber reinforced modified PPO; b) electronics component tray, 15% carbon fiber reinforced ABS; c) electronics hybrid carrier, 15% carbon fiber + 15% glass fiber reinforced flame retardant PBT polyester.

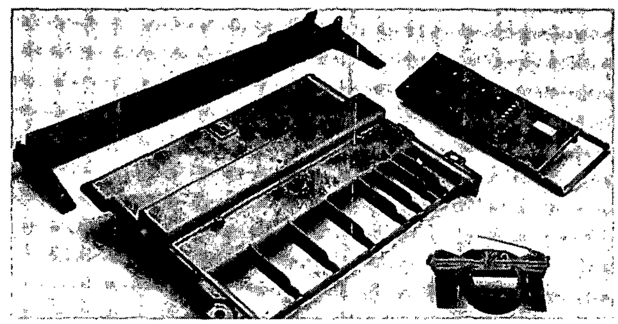

Figure 5. Static Dissipating Pan Carbon Fiber Applications. a) Computer printer ribbon cartridge bar, 15% PAN carbon fiber + 15% glass fiber reinforced nylon 6/6; b) instrument housing, 15% PAN carbon fiber reinforced polycarbonate U.L. 94V-0; c) platen/cover for a photo type setting machine, 15% PAN carbon fiber reinforced polycarbonate; d) photo-sensing smoke alarm cell housing, 40% PAN carbon fiber reinforced nylon 6/6.

Because of the limited thermal stability of the additives used, formulations are confined to the styrenics, polyolefins and PVC. Some parts made from these materials can have a greasy feel and appearance which makes printing and labeling difficult. They offer translucency in the end product and are available in pigmented grades. The antistatic compounds are tailored for applications such as linear chip magazines (see Figure 2), and storage bins, medical apparatus, and business machine components.

Summary

The following compares antistatic and static dissipative features which should be analyzed when considering plastic composites for an ESD control application.

Static Dissipating Thermoplastic Composites

1. 10^2 - 10^6 ohms/sq.
2. Will protect sensitive electrical components from high ESD voltages (4,000 - 15,000 volts)
3. Conductive fillers - primarily carbon black powders and PAN carbon fiber. Other additives include pitch carbon fiber, nickel coated carbon fiber, aluminum flake and aluminum fiber.
4. Thermoplastic polymers are unlimited when considering the full range of conductive fillers.
5. Conductivity is permanent - conductive additives cannot be removed by chemical washes.
6. Thermal stability of the composite is not limited by the conductive additives.
7. Color is limited to black with the carbon powders. Limited colors are available in the other conductive composites.
8. Application areas are vastly expanded beyond packaging and handling, including business machine structural components, medical devices, and instrument housings.

Anti-Static Thermoplastic Composites

1. 10^9 - 10^{13} ohms/sq.
2. Will protect moderately sensitive electrical components from low ESD voltages (up to 1,000 volts).
3. Conductive additive - ethoxylated fatty amines.
4. Thermoplastic polymers are limited to styrenics, PVC, polypropylene and polyethylene.
5. Conductivity is not permanent - chemical washes can remove the conductive surface layer, requiring a time period (several days) for the additives to regenerate themselves by migrating to the surface.
6. Conductive additives have limited thermal stability, thus restricting their use to the low melt (415° F maximum) polymers.
7. Colorable, with many of the unpigmented formulations being translucent.
8. Application areas are generally limited to electronics packaging and handling.

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