# ELECTRICALLY CONDUCTIVE PLASTICS

Static-charge buildup can be a serious problem for plastic parts, causing sparking and surface-dust pickup. In some applications, such as electronic equipment, high-velocity conveyors, and web-handling systems, the problem is particularly pernicious.

New families of plastics have been specifically designed for electrical conductivity. They combine the traditional low-cost flexibility in design of plastic parts with the ability to dissipate static charges. Electrostatic charges are generated on the surfaces of poor electrical conductors. The charge must be conducted to ground to avoid sparking and dust pickup.

Accumulated surface charges can be dissipated by conduction within or along the surface of the material and gradual decay to the air. The charge-dissipation process, which involves ion migration from surface to surface, or surface to air, is extremely slow in non-conductive plastics. To speed up the process, conductive fillers such as carbon-black powder, carbon fibers, and metallic fibers are incorporated.

### How Much Conductivity?

Material resistivity, the reciprocal of conductivity, measures the electrical charge conducted through and along the material surface. Material having a low surface resistivity will exhibit good anti-static properties.

Metallic conductors (copper, aluminum) have surface resistivities ranging from $10^{-4}$ to $10^{-6}$ ohm. Polymeric insulators have resistivities of $10^{14}$ to $10^{16}$ ohm. Bridging this conductance gap are the carbon or metal-filled polymer systems. "Conductive" compounds have $10^0$ to $10^2$ ohm resistivities, and "anti-static" compounds have $10^2$ to $10^6$ ohm resistivities.

### How About Using EMI Materials?

Materials for attenuating electromagnetics interference (EMI) are electrically conductive enough to dissipate static charge, but the converse is not necessarily true.

EMI-attenuation properties depend on both electrical-conduction and energy-reflection properties. Metal-filled and carbon-fiber reinforced plastics perform well in both of these modes and are currently used both for static dissipation and for EMI attenuation.

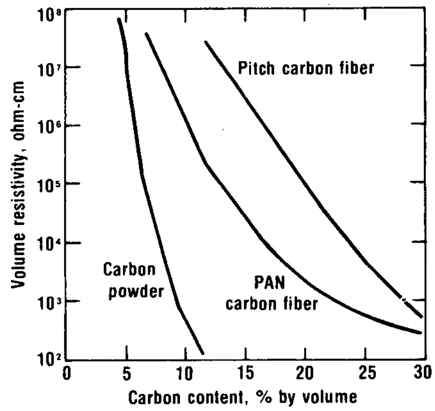
Stray electromagnetic interference (EMI) must be guarded against in digital and analog logic circuits for computers or control systems. In these cases, EMI-attenuating materials offer protection against stray radio frequency interference and static discharge.

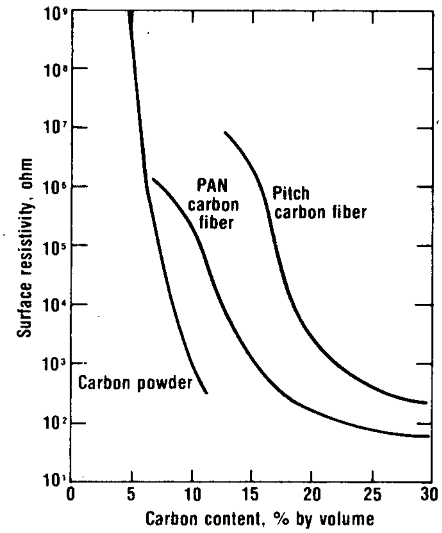
Materials functioning solely as static dissipators are generally used in moving machinery (textile, paper handling, business machines) as bearings, rollers or conveyors to dissipate surface-contact charges continuously.

### Comparing the Conductive Fillers

Conduction properties of a conductive-filled plastic depend on the number of particle contacts and the average inter-particle distance. These parameters, in turn, are a function of particle shape, concentrations, and dispersion.

Three different types of carbon filler systems have been evaluated: 0.25-in. (6.4-mm) PAN carbon fibers, milled-pitch carbon fibers, and conductive carbon powder. All composites were melt-extruded, and injection-molded specimens were tested using procedures standardized in ASTM D257-78. Volume resistivity was measured through a 0.125-in. (3.2-mm) disk. Measurements were taken at low voltages (1.5 and 9 v).




*Carbon-powder composites are more conductive than carbon-fiber composites. But resistivity of carbon-fiber composites varies less as carbon volume fluctuates.*

As shown in the graphs comparing the three carbon-filler systems, carbon-powder composites are more conductive than chopped-carbon fiber composites for carbon-powder volume loadings of 6% and 11%. But equally important is the relatively steeper slope of the carbon-powder compounds over the surface-resistivity range of interest for static-charge dissipation ($10^2$ to $10^6$ ohm). Considering a typical compounding variation of ± 1% in volume, surface, resistivity of carbon powder may vary, two to three orders of magnitude, while PAN and pitch fibers vary within a single power of ten. There is, therefore, greater control over electrical resistivity in PAN and pitch fiber series.

The generally lower resistivity of 0.25-in. (6.4-mm) PAN-fiber compounds over the milled-pitch fiber compounds is attributed to the higher aspect ratio of the PAN fibers. Longer fibers reduce the concentration of conductive fiber needed for electrical conductivity.

**Carbon-fiber-reinforced nylon 6/6**

| Property | Method | Units | 0.25 in. PAN fibers 20% | 0.25 in. PAN fibers 30% | 0.25 in. PAN fibers 40% | Milled-pitch fibers 20% | Milled-pitch fibers 30% | Milled-pitch fibers 40% |
|---|---|---|---|---|---|---|---|---|
| Specific gravity | D792 | — | 1.23 | 1.28 | 1.34 | 1.25 | 1.30 | 1.37 |
| Tensile strength | D638 | psi | 28,000 | 35,000 | 40,000 | 16,000 | 17,500 | 19,000 |
| | | (MPa) | (193) | (241) | (278) | (110) | (121) | (131) |
| Tensile elongation | D638 | % | 3-4 | 3-4 | 3-4 | 3-4 | 3-4 | 2-3 |
| Flexural strength | D790 | psi | 42,000 | 51,000 | 60,000 | 24,000 | 25,000 | 28,000 |
| | | (MPa) | (290) | (352) | (414) | (165) | (172) | (193) |
| Flexural modulus | D790 | $10^6$ psi | 2.4 | 2.9 | 3.4 | 1.0 | 1.3 | 1.8 |
| | | (MPa) | (16,500) | (20,000) | (23,400) | (6,890) | (8,960) | (12,410) |
| Izod impact strength | D256 | | | | | | | |
| Notched, 0.25 in. | | ft-lb/in. | 1.1 | 1.5 | 1.6 | 1.3 | 1.5 | 1.7 |
| | | (J/m) | (59) | (80) | (85) | (69) | (80) | (91) |
| Unnotched, 0.25 in. | | ft-lb/in. | 8.0 | 12.0 | 13.0 | 7.0 | 13.0 | 14.0 |
| | | (J/m) | (430) | (640) | (690) | (370) | (690) | (750) |
| Heat-deflection temp. at 264 psi | D648 | °F | 495 | 495 | 500 | 475 | 480 | 485 |
| | | (°K) | (530) | (530) | (533) | (519) | (522) | (525) |
| **Surface resistivity** | D257 | ohm | $10^3$ | $10^2$ | $10^1$ | $10^6$ | $10^3$ | $10^2$ |

**Static-conductive thermoplastics***

| Property | Method | Units | Nylon ST | Poly-acetal | Polypro-pylene | Nylon 6/6 with 15% glass fiber | Poly-phenylene oxide alloy | Poly carbonate with 30% glass fiber |
|---|---|---|---|---|---|---|---|---|
| Specific gravity | D792 | — | 1.11 | 1.43 | 0.94 | 1.29 | 1.12 | 1.47 |
| Tensile strength | D638 | psi | 6,500 | 5,500 | 3,000 | 10,000 | 6,000 | 13,000 |
| | | (MPa) | (45) | (38) | (21) | (69) | (41) | (90) |
| Tensile elongation | D638 | % | 8.0 | 2.0 | 11.0 | 2.0 | 2.0 | 2.0 |
| Flexural strength | D790 | psi | 11,500 | 10,500 | 3 600 | 20,000 | 9,000 | 15,500 |
| | | (MPa) | (79) | (72) | (25) | (138) | (62) | (107) |
| Flexural modulus | D790 | 1000 psi | 325 | 420 | 110 | 850 | 420 | 1,040 |
| | | (MPa) | (2,240) | (2,900) | (760) | (5,860) | (2,900) | (7,170) |
| Izod impact strength | D256 | | | | | | | |
| Notched, 0.25 in. | | ft-lb/in. | 1.5 | 0.4 | 3.2 | 1.0 | 0.3 | 1.2 |
| | | (J/m) | (80) | (21) | (170) | (53) | (16) | (64) |
| Unnotched, 0.25 in. | | ft-lb/in. | 15.0 | 2.5 | 25.0 | 3.5 | 2.3 | 4.2 |
| | | (J/m) | (800) | (130) | (1,300) | (190) | (120) | (220) |
| Heat-deflection temp. at 264 psi | D648 | °F | 215 | 230 | 180 | 485 | 265 | 300 |
| | | (°K) | (375) | (383) | (355) | (525) | (403) | (422) |
| **Surface resistivity** | D257 | ohm | $10^5$ | $10^2$ | $10^5$ | $10^3$ | $10^4$ | $10^4$ |

*Contain carbon powder.

**Comparison of polycarbonate compounds**

| Property | Method | Units | No fillers | 30% glass fiber | 15% PTFE | 15% PTFE, 30% glass fiber | 15% PTFE, 30% glass fiber, carbon powder | 30% PAN fiber | 30% pitch fiber |
|---|---|---|---|---|---|---|---|---|---|
| Tensile strength | D638 | psi | — | 18,500 | 7,000 | 17,5000 | 6,500 | 24,000 | 11,500 |
| | | (MPa) | — | (128) | (48) | (121) | (45) | (165) | (79) |
| Tensile elongation | D638 | % | — | 4-6 | — | — | 1-2 | 3-4 | 2-3 |
| Flexural strength | D790 | psi | — | 28,000 | — | — | 11,000 | 36,000 | 17,000 |
| | | (MPa) | — | (193) | — | — | (76) | (248) | (117) |
| Flexural modulus | D790 | $10^6$psi | — | 1.2 | 0.3 | 1.2 | 1.15 | 1.9 | 1.1 |
| | | (MPa) | — | (8,300) | (2,100) | (8,300) | (7,900) | (13,100) | (7,600) |
| Izod impact strength | D256 | | | | | | | | |
| Notched, 0.25 in. | | ft-lb/in. | — | 3.7 | 2.0 | 2.0 | 0.7 | 1.8 | 3.0 |
| | | (J/m) | — | (200) | (110) | (110) | (37) | (96) | (160) |
| Unnotched, 0.25 in. | | ft-lb/in. | — | 17.0 | — | — | 1.4 | 10.0 | 5.6 |
| | | (J/m) | — | (910) | — | — | (75) | (530) | (300) |
| Wear: K factor | LNP #3 | $10^{-10}$in.$^3$-min/ ft-lb-hr | 2,500 | 180 | 75 | 30 | 88 | 85 | 145 |
| | | ($10^{-6}$ mm$^3$ • min/ m • N • hr) | (3,020) | (217) | (91) | (36) | (106) | (103) | (75) |
| Coefficient of friction | — | Static | 0.31 | 0.23 | 0.09 | 0.18 | 0.16 | 0.18 | 0.15 |
| | | Dynamic | 0.38 | 0.22 | 0.15 | 0.20 | 0.18 | 0.17 | 0.20 |
| **Surface resistivity** | D257 | ohm | $10^{16}$ | $10^{16}$ | $10^{16}$ | $10^{16}$ | $10^5$ | $10^3$ | $10^4$ |

### Strength, Stiffness, Wear

PAN carbon fibers are highly reinforcing in a thermoplastic composite, making significant contributions to tensile and flexural strengths. They also give it superior stiffness, as seen in high flexural modulus values. Several carbon-powder-filled composites offer superior elongation and Izod impact-strength properties.

Other important considerations in carbon-filled compounds are wear and friction properties. Addition of carbon fibers to thermoplastic systems greatly reduces wear rate, but the same phenomenon is not observed in carbon-powder-filled compounds.

The addition of carbon powder to PTFE/fiber-glass-filled polycarbonate produces a threefold increase in the wear factor of the composite. In contrast, wear factor of a 30% PAN-fiber reinforced polycarbonate is half that of a 30% glass-fiber-reinforced polycarbonate and approaches the wear factor observed for a 15% PTFE lubricated system. Carbon fibers offer a reduction in friction and wear and at the same time provide superior mechanical properties.

### Summary

In imparting electrical conductivity to a thermoplastic composite, conductive carbon powder is better than 0.25-in. (6.4-mm) PAN carbon fiber which, in turn, is better than milled-pitch carbon fiber. The effect can be attributed to the relatively high surface purity of the conductive carbon powder.

Because of the steep resistivity vs. carbon-loading curve, use of carbon-powder-filled compounds is limited to electrical applications in which a wide range of composite conduction values is allowable.

At loadings greater than 15% to 20% volume of carbon fibers, electrical conductivity increases minimally with further addition of fibers.

PAN fiber is better than milled-pitch fiber in providing reinforcement to thermoplastic composites. Both are much better than carbon-powder.

In imparting wear resistance to polycarbonate composites, PTFE does the most good. In order of decreasing value, PTFE > PAN fiber > milled pitch fiber > glass fiber > carbon powder.

### What Conductive Fillers Are Used?

Conductive carbon blacks have long been used to impart antistatic and conductive properties to elastomers and thermoplastics for wire and cable. They are irregularly shaped particles composed of partially graphitized nodules fused into grape-like aggregates.

Conductivity of the composite is limited by electrical conductivity of the carbon powder, typically $10^5$ to $10^6$ times less than metals. Electrical properties of carbon powders vary considerably with particle size, degree of aggregation, and chemical purity of the surface. These finely divided particles are easily dispersed in a polymer melt and, at high enough volume loadings, will increase conductivity.

Carbon fibers provide a graphitic conductor of different geometry and surface chemistry. Organic fibers of polyacrylonitrile (PAN) or hydrocarbon pitch are furnace-graphitized and then surface-treated with sizings to increase bulk density and with chemical coupling systems to help wet out and disperse the fibers in the polymer melt. These fibers have excellent mechanical properties, including flexural modulus exceeding that of glass fibers.

High-aspect-ratio aluminum flakes and fibers have recently become commercially available. Aluminum-thermoplastic composites are being used in electromagnetic interference (EMI) shielding applications because of their energy reflectivity as well as electrical conductivity.

Compression moldings made with roll-milled aluminum compounds have exhibited relatively high electrical conductivity. But injection-molded specimens made from melt-extrusion-compounded composites yielded lower conductivity, attributed to curling and breakage of the aluminum particles during high-shear processing. As a result, more consistent and conductive electrical properties have been obtained with carbon-powders and fibers in injection-molding compounds.

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