Seeking Neutral: Controlling Charge in Auto Fuel Systems

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The flow of fuel in automotive fuel systems creates a static charge. While this is not a problem if the charge dissipates as it forms, it can become a serious problem if the electrostatic potential builds to the point where arcing occurs. Repeated arcing can pierce a hole through a plastic fuel-system component, which will cause fuel or vapors to escape. During refueling, even a single electrostatic discharge can cause a thermal event.

Several trends in automobile fuel systems have heightened the potential for charge buildup. One is the growing use of plastics, which has generally been a boon to the industry. As insulators, however, plastics heighten electrostatic issues. Another is the shift to fuel injection, which prompted designers to move the fuel pump from near the engine to the fuel tank. This change increased the volume of fuel through the fuel lines, increasing charge accumulation. Charge accumulation may increase in the future as fuel pressure is boosted to aid fuel injection. In addition, some oxygenates blended into fuels can increase static charge as they flow through the system.

All plastic elements that carry fuel—filler necks, fuel modules, filter, lines, fuel rails, onboard vapor recovery refueling systems and more (*Table 1*)—receive close scrutiny regarding electrostatic charge. The industry's fuel-system ESD standard, Society of Automotive Engineers (SAE) J1645, "Fuel System—Electrostatic Charge," includes test methods for measuring the electrostatic characteristics of materials, components, and assemblies to ensure they will not cause electrostatic hazards in vehicles.

Fuel systems are governed by many standards and regulations. For instance, U.S. Dept. of Transportation FMVSS 301 says fuel systems must withstand impacts of 45 mph without rupture. Also, the SAE J1681 "Gasoline, Alcohol, and Diesel Fuel Surrogates for Materials Testing" standard defines fuel recipes for evaluating fuel-system materials. It determines the chemical resistance required in fuel-system polymers. In addition, permeability limits in California's Low Emission Vehicle II and Partial Zero Emission Vehicle mandates regulate the amount of fuel vapors allowed to escape through materials like plastics and elastomers.

Plastics That Limit Charge Buildup

Polymers dissipate static charge when they contain conductive additives like carbon powder, carbon or stainless-steel fibers, or selected nanomaterials. Plastic is an insulator until a threshold loading of one of these additives alters a material's resistance to the point where its percolation curve drops to the conductive state (*Fig. 1*).

Conductive additives affect the elongation, impact strength, modulus, and other mechanical properties of a resin (*Table 2*). Carbon fiber grades are stiffer and stronger and elongate less than unfilled polymers. They also usually have improved friction and wear resistance. Carbon powder grades allow moderate elongation and are similar in strength and stiffness to the neat polymer. Grades made with stainless-steel fiber offer the best combination of mechanical performance and static dissipation. These grades have moderately higher stiffness and strength and good elongation versus unfilled grades.

The effects of conductive additives can be seen in acetal copolymer, the most common family of polymers used in fuel-system components (*Table 3*). Consider stiffness—one standard, unfilled acetal copolymer (Celcon® M90) has a tensile modulus of about 3000 MPa. The modulus of the carbon fiber–filled grade (Celcon® EF10), which is based on the standard grade, jumps dramatically to 8400 MPa, while the moduli of the carbon powder and stainless-steel grades are much closer to that of the unfilled resin.

Designers and molders must ensure that a conductive additive is sufficiently dispersed to give parts the best possible electrical and mechanical properties. Uneven dispersion can make conductivity spotty and render a part nonconductive. Designers use uniform wall thicknesses and generous fillets and corner radii to keep material flowing freely and to prevent a filler or fiber from concentrating in part geometries such as corners.

Molders take steps to ensure the integrity of conductive fibers. They use general-purpose screws having non-aggressive profiles that are sized to reduce shear and thus fiber breakage. They also size sprues and bushings to reduce shear, use larger gates than with unfilled resins (typically about 2 mm in diameter), and avoid long barrel-residence times. Molders must pre-dry grades containing conductive fillers that draw moisture into the polymer.

Assembly also has special considerations. For instance, the drop in elongation at break caused by conductive additives can make snap-fits more difficult to use and make it more difficult to join parts by spin, vibration, or hot-plate welding.

General ESD Considerations

ESD fuel-system measurement occurs at three levels: the first certifies polymers for resistance and static dissipation; the second evaluates components to ensure that processing does not significantly degrade the polymer's ability to dissipate charge; and finally, assemblies are tested to ascertain that bonding among components allows the charge to travel freely to ground.

Resistance is used to classify the electrostatic-dissipation characteristics of materials. The ESD Association classifies material having a resistance below 10^4 Ohms as conductive, between 10^4 and 10^{11} Ohms as static-dissipative, and above 10^{11} as insulating. Unfilled plastics are usually insulators. Although these classifications were developed primarily for static-safe packaging materials, they are also referenced throughout the static-control industry. For potentially explosive environments, a resistance below 10^6 is generally specified.

Conductive polymers are defined by their volume resistivity, as opposed to surface resistivity, because current flows through them and not just along the surface. Volume resistivity (in Ohm-cm) is the measured resistance times the area of the measuring electrode or material surface, whichever is smaller, divided by sample thickness. The resistance of loaded thermoplastics is nonlinear and is a function of the test voltage applied.

Resistance and static-dissipation measurements should be performed using surface-contacting electrodes that simulate real-world surface contact. Standard test probes—pinpoint probes that come with digital multimeters or alligator clips—should not be used. The former lack sufficient contact area, while the latter make random point surface contact and could also punch through the surface and contact the conductive filler or fiber. Silver-paint electrodes should also be avoided. They can give false low-resistance readings because the paint makes total surface contact and can penetrate the surface layer to make contact with the conductive additive, neither of which occurs under normal conditions.

Resistance measurements apply a continuous current at low voltage between a pair of defined electrodes, while dissipation testing applies a finite current at high voltage across the test sample. Voltage in the latter case is stored in the capacitance of the material before discharge. Resistance and static dissipation are measured using clamping electrodes with conductive rubber pads. The pad on the smaller electrode measures 0.25 x 0.125 inch (6 x 3 mm), so it can enter small components and fuel lines having diameters down to 0.25 inch (6 mm). The pad on the larger electrode measures 0.25 x 0.25 inch (6 x 6 mm) and is used to measure the larger outer surface area of the component.

When measuring resistance and static dissipation, follow set procedures on how to prepare and configure samples, on the equipment to use and how it is set up, and on the environmental conditions to control. In terms of the latter, relative humidity must be controlled for parts that have been fuel-soaked. Also, specify how data will be reported, e.g., minimum, maximum, and average resistance in Ohms, and how system performance will be verified using fixed resistors prior to actual testing.

Tests for Electrostatic Properties

Test procedures for measuring volume resistance, from which volume resistivity is calculated, and electrostatic dissipation (decay) to certify the ESD performance of a polymer differ from those used for testing components and assemblies. Material testing is performed on standard flat plaques. Volume-resistance measurements follow the procedures in ESD Association Standard Test Method ESDA STM 11.12, “Volume Resistance Measurements of Static Dissipative Planar Materials.” These procedures were initially created for static-safe packaging materials, but are easily adapted for fuel-system polymers. Instruments should have a measuring range from less than 10^3 to 10^8 Ohms. Measurements are typically performed at 100 V and 10 V. For safety reasons, the maximum current is limited to 5 milliamps when the test voltage is 100 V or more.

The static decay of material plaques is usually measured in accordance with Mil. Standard 3010, Method 4046.1, “Antistatic Properties of Materials.” This test first charges a plaque to 5000 V through a pair of isolated electrodes and then discharges it by grounding the electrodes. An electrostatic field meter measures the time for the voltage on the plaques to decay to either 10% or 1% of the applied voltage. The acceptable dissipation time to 10% should be less than 0.5 second, although for conductive materials it is usually less than 30 milliseconds.

SAE J1645 recommends that the volume resistance of fuel-system components and assemblies be less than 10^6 Ohms. The maximum resistance of an assembly should reflect what is specified over the longest path to ground for that assembly. Measurements are specified at 100 V and at a lower voltage, usually 10 V.

Assembly-dissipation time, which is a function of resistance and capacitance, is measured using a charged-plate monitor. The static dissipation of an assembly should decay from 1000 V to 100 V in less than 0.5 sec. The test may also be performed using a drop from 5000 V to 500 V within 0.5 sec.

Conclusion

Electrostatic charge in plastic automotive fuel-system components and assemblies must be dissipated before it can build to the point where a static discharge can occur. ESD is a growing issue, given the increasing use of plastics in fuel systems and the movement toward greater fuel pressures to aid combustion.

Considerations for controlling ESD in fuel systems extend from the choice of polymer and part design to molding. When conductive fillers and fibers are added to a polymer, they not only allow charge to flow to a ground but also change the resin's strength, elongation, and other mechanical properties. These changes must be balanced against specifications given in other standards, including impact strength and chemical resistance.

The materials, components, and assemblies used in fuel systems must be certified to have the electrical resistance and electrostatic dissipation specified. The procedures for these tests are defined in a number of industry standards and should be followed closely. Measuring instruments for performing these tests are commercially available.

Click here for tables and figure.

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Test Methods for Electrostatic Dissipation

The following standards and practices apply to measuring electrostatic dissipation in materials and components:

- Society of Automotive Engineers J1645 "Fuel System—Electrostatic Charge"
- ASTM-D991-1989: "Standard Test Method for Rubber Property—Volume Resistance of Electrically Conductive and Antistatic Products"
- UL 330: "Hose and Hose Assemblies for Dispensing Flammable Liquids"
- ESD Association
  - ESDA Adv1.0: Glossary of Terms
  - ESD STM 11.11-2001: "Surface Resistance Measurement of Static Dissipative Planar Materials" (to be reviewed & modified in 2005)
  - ESD STM11.12-2000: "Volume Resistance Measurements of Static Dissipative Planar Materials" (to be reviewed & modified in 2005)
  - ESD STM11.13-2004: "Two-Point Resistance Measurement of Conductive, Dissipative and Insulative Items"
  - ESD TR 02-99: "High Resistance Ohmmeters—Voltage Measurements"
- Military Specifications
  - Mil. Std. 3010, Method 4046.1 (Formerly FTM 101C, Method 4046.1) "Antistatic Properties of Materials"
  - Mil-PRF-81705D (Formerly Mil-B-81705D)

Table 1. Typical Polymer Applications in Fuel Systems.*

Component Acetal PPS PBT HDPE HTN N6/6 N12

Canisters x x x

Fuel caps x x

Fuel filler pipes x x x
Fuel filter housings x x
Fuel lines x
Fuel pump components x x x
Fuel rails x x x
Fuel sending unit flanges x x
Fuel tanks x
Inlet housings (fuel cap receivers) x
Quick connects x x x x
Throttle bodies x x x
Valves:
Fuel rollover valves x x x
Fuel fill limit valves x x
ORVR valves x
Inlet check valve filler pipes x x

**Acetal is acetal copolymer; PPS is polyphenylene sulfide; PBT is polybutylene terephthalate; HDPE is high-density polyethylene; HTN is high-temperature nylon; N6/6 and N12 are nylon 6/6 and nylon 12.*

Table 2. How Conductive Additives Affect Engineering Polymers.*

Property	**Carbon Fiber**	**Carbon Powder**	**Stainless-Steel Fiber**
Stiffness, strength	Higher	Similar	Slightly higher
Elongation	Low	Moderate	Good
Shrinkage	Anisotropic	Isotropic	Minor anisotropy

*Compared with unfilled polymer.

Table 3. Properties for Selected Acetal Copolymer ESD Grades.*

Property	**Standard Grade****	**Carbon Powder****	**Carbon Fiber****	**Stainless Steel****
Physical				
Density, kg/m^3	1410	1420	1420	1470
Melt flow range, g/10 min.	9.0	2.0	4.6	2.0
Spiral flow range, % of standard grade	100	86	90	90
Mold shrinkage (flow direction), %	1.9	1.7	0.8	1.9
Mold shrinkage (transverse direction), %	2.0	1.5	1.1	1.7
Mechanical				
Tensile modulus (1 mm/min), MPa	3000	3170	8400	3100
Tensile strength at yield (50 mm/min), MPa	67	58	N/R	63
Tensile strength at break (50 mm/min), MPa	N/R	N/R	76	N/R
Tensile strain at break (50 mm/min), %	37	7	2	20
Charpy notched impact strength @ 23°C, KJ/m^2	5.8	2.6	4.2	4.5
Notched impact strength (Izod) @ 23°C, KJ/m^2	5.5	4.7	4.2	
Electrical				
Volume resistivity, Ohm-cm	8×10^{14}	8×10^{3}	5×10^{4}	3×10^{2}
Surface resistance, Ohms	3×10^{16}	4×10^{2}	6×10^{1}	2×10^{3}
Thermal				
DTUL @ 1.8 MPa, °C	107	102	160	100

** All ESD resins shown have a maximum resistance of 10^6 Ohms or 90% static decay in under 0.5 sec when charged by 1-KV minimum source.*

*** Categories correspond to the following acetal copolymer grades:*

– Standard grade: Celcon® M90 and Hostaform® C9021 acetal copolymer.

- *Carbon powder-filled grade: Duracon® EB-08 acetal—general purpose, good strength.*
- *Carbon fiber-filled grade: Celcon® EF10 acetal—high strength and stiffness.*
- *Stainless steel-filled grade: Celcon® CF802 acetal—best overall mechanical performance and static dissipation.*

Fig. 1. Conductive percolation curve.

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High
Resistivity
Low
Low Conductive Additive Loading High
Required additive threshold loading