

Polymers 2022-01

Technical Bulletin

Conductive Compounding

Introduction

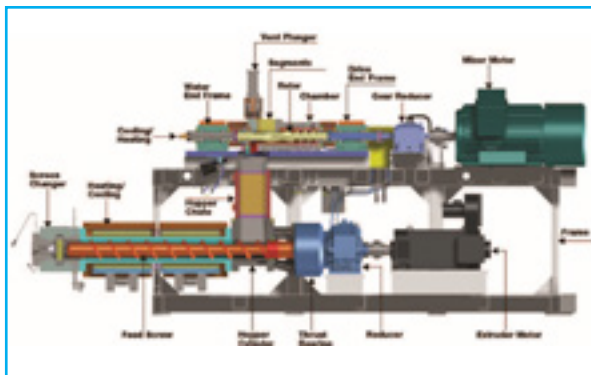
Advances in hybrid (HV) and electric vehicle (EV) technology have increased the demand for thermoplastic conductive compounds for electrostatic discharge applications (ESD), electromagnetic interference (EMI), and radio-frequency interference (RFI) shielding. All these functions are enabled by conductive fillers such as carbon black.

Orion Engineered Carbons has been focusing on the nature of carbon black conductivity, conductive black use in these HV and EV applications, and other thermoplastic conductive applications. To explore how to better support these applications, Orion collaborated with FARREL POMINI of Ansonia, Connecticut, and assessed carbon black morphology and processing effects on conductivity in polycarbonate compounds.

Experimental Design

The experimental design involved 30 MI polycarbonate, 3 – conductive carbon blacks at several dosages, and compounding on a FARREL POMINI Compact Processor (CP) continuous mixing technology. This machine consists of a continuous mixer mounted over an extruder. The response variables included machine specific energy, resistivity, and impact results.

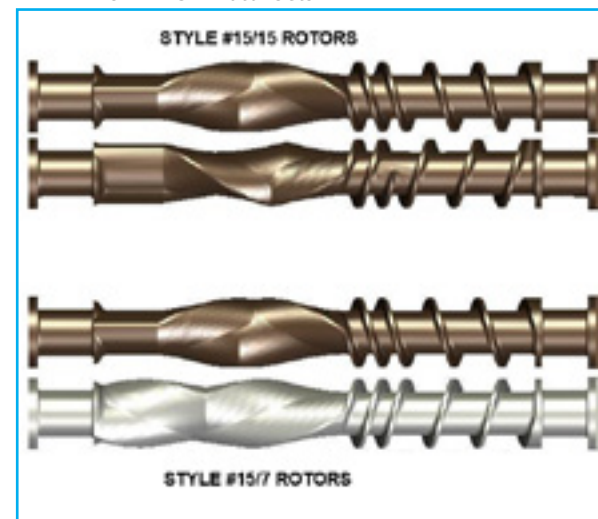
Figure 1
FARREL POMINI CP



Compounder consisting of a continuous mixer and extruder to separate the mixing and pelletizing process

The first step of the experiment involved producing several PC compounds using OEC and a recognized conductive black. This step also included evaluation of two rotor sets that impart different levels of shear during mixing in the first stage of compounding.

Figure 2
FARREL POMINI CP– Rotor Sets



15/7 and 15/15 combinations used in the experiment

As figure 2 shows, the 15/7 combination imparts better distributive mixing into a compound compared to the 15/15 combination. This distinction is important, because conductive compounds can easily be over-dispersed and see their resistivity properties degrade (become more resistive).

Experimental Design – Process Conditions

FARREL POMINI Compact Processor machine settings and temperature profile were fixed for all compounding runs; consequently, variation in machine specific energy were driven by variation in carbon black dosage and particle size and shape. Table 1 and 2 illustrate these conditions:

Table 1

Machine Conditions All Runs	
Roter Speed (rpm)	700
Total Feed Rate (kg/hr)	15
Orifice Position (%Open)	50%
Vent Position	Closed
Dams	None
MFI PC Resin (g/10 min)	30

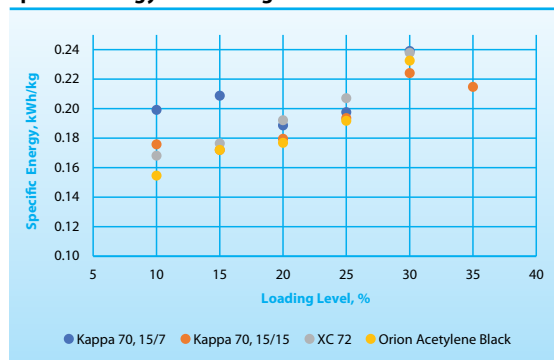
Table 2
Temperature Profile All Runs

Zone	PC
Zone 1 (°C) - Hopper	120
Zone 2 (°C) - Chamber	200
Orifice (°C)	230
Extruder Hopper (°C)	220
Extruder Cylinder (°C)	230
Extruder Head (°C)	280

Note all compounds were strand pelletized and then prepared for applications testing

Results and Analysis

The first set of data drawn from the compounding runs were specific energy results. Figure 3 shows that conductive carbon black dosage, particle size and shape, and rotor set selection show influence specific energy.

Figure 3
Specific Energy vs. Loading Level CB in PC

As black dosage increases, the load – specific energy - on the CP machine increases. Higher black dosage displaces polymer in the compound and imparts higher viscosity – more resistance to flow. Carbon black particle

size and shape also shows influence on specific energy results. Combination of higher surface area and higher OAN push compound viscosity higher and the response of higher machine specific energy (see Table 3 below).

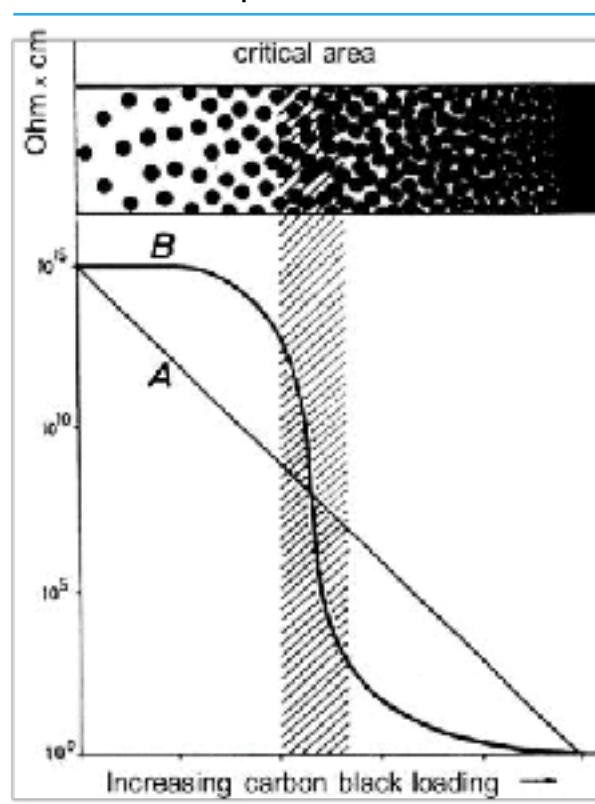
Table 3

Carbon Black Particle Size and Shape	Surface Area (m ² /gm)	OAN (cc/100 gm)
Orion Acetylene Black	70	280
Orion PRINTEX® Kappa 70	140	170
Incumbent Standard (STD) Black	250	170

Rotor set selection appeared to have a bigger influence on specific energy at lower carbon black dosage. One line of thinking is the 15/7 set – lower shear design required more time to shear heat and melt polymer at 10 and 15 percent black dosages. At higher black dosages, the specific energy difference between the 15/7 and 15/15 – higher shear rotor set was not as pronounced. The rotor effect will be explored further in the applications test results review.

Resistivity – Impact Properties

Conductive black compounding targets are usually expressed in terms Ohms-cm or Ohms per square resistivity units. A key objective in developing conductive compounds is to hit a consistent resistivity result and retain as large a percent of impact and mechanical properties as possible. The appearance of stable resistivity is illustrated in Figure 4:

Figure 4
Model Conductive Compound Percolation Curve

Compound conductive black dosage that lands outside of the high slope, rapidly changing resistivity percolation zone helps ensure consistent resistivity as the compound moves from product development to commercialization. In this case study, Table 4 shows

that stable resistivity, for all blacks, exists at >20 weight percent carbon black. This suggests that at that dosage, these compounds would fit well in electrostatic discharge (ESD) applications that require 10^3 to 10^6 ohms – cm.

Figure 5
Surface Resistivity (Ohm-cm)

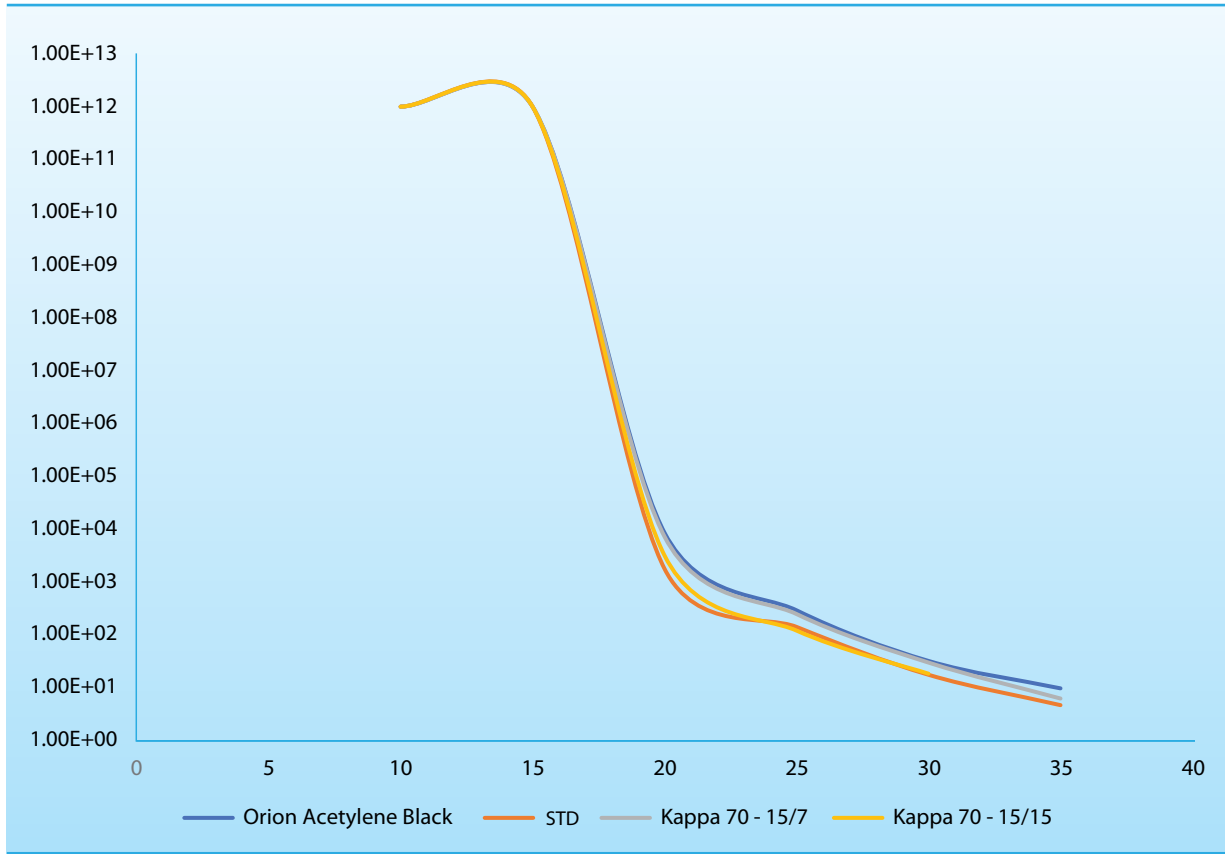
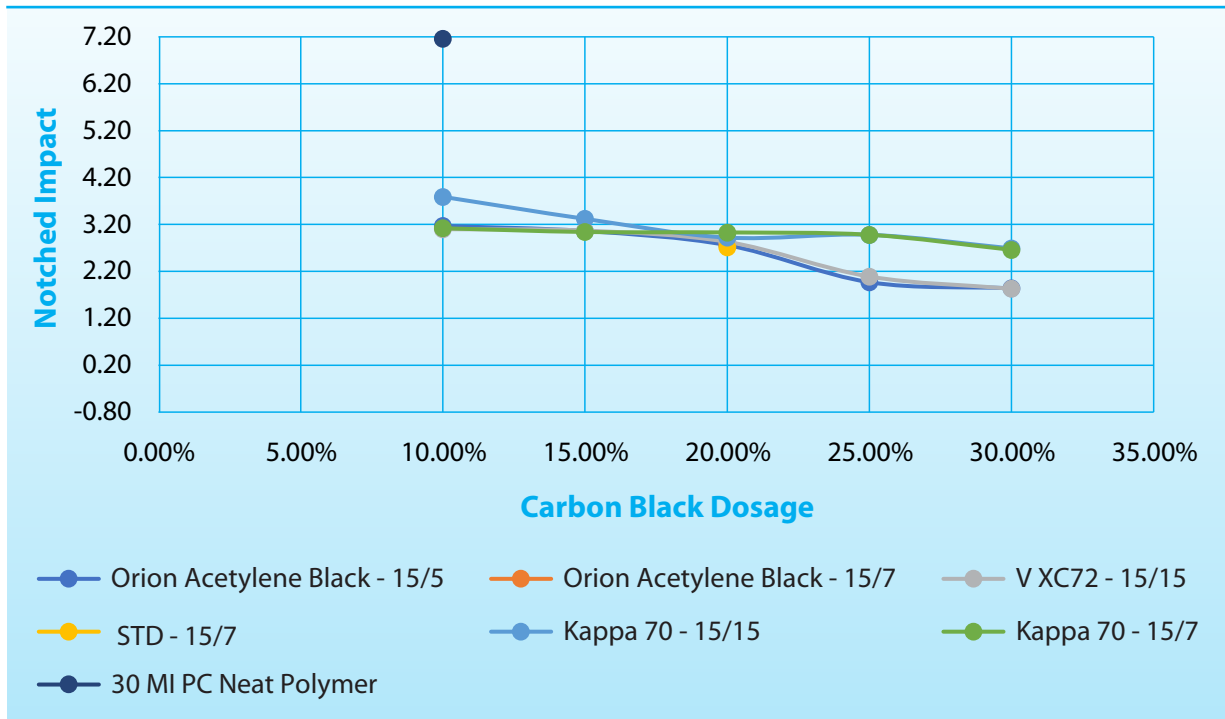


Figure 6
Molded Notched Impact (kJ/m²)

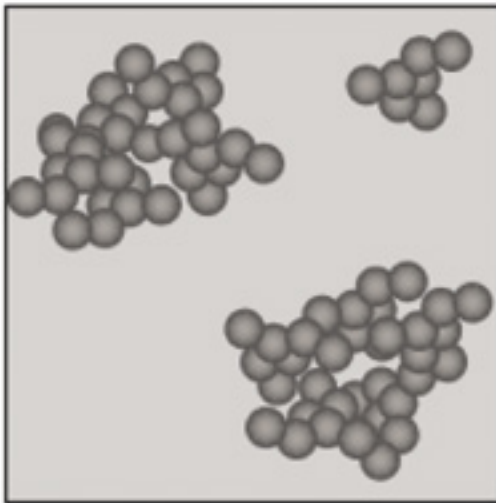


Naturally, the initial focus of conductive compound developments are imparting stable resistivity around the target resistivity, but impact properties must also be considered to ensure the conductive compound meets customers' expectations in their applications.

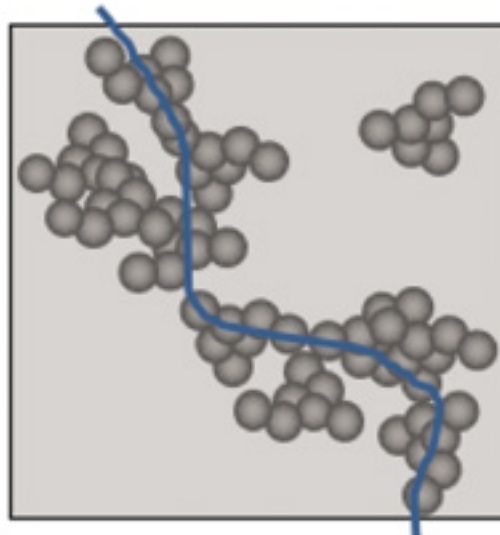
Figure 6 illustrates that any amount of conductive carbon black compounded into the polycarbonate compound diminishes the polymer's impact properties but note that at the commercially important ESD carbon black dosages, Kappa 70 shows best impact retention both in 15/15 and 15/7 rotor set compounds

The loss of impact occurs as carbon black displaces polycarbonate polymer, and although dispersion might be acceptable, even small – undispersed carbon black agglomerates can contribute to crack propagation in the notched impact test and in the end application. Please note that although better dispersion enhances mechanical properties in most carbon black applications, conductive compounding requires an optimization that balances the need to establish a conductive network in the polymer that yields consistent electrical properties and minimizes mechanical property loss. Figure 7 shows that formation of the conductive carbon black network is critical to meeting customers' resistivity targets.

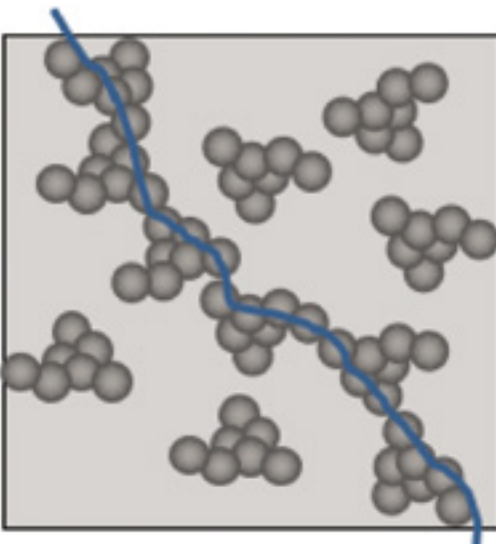
Figure 7
Good Dispersion – Good Conductivity



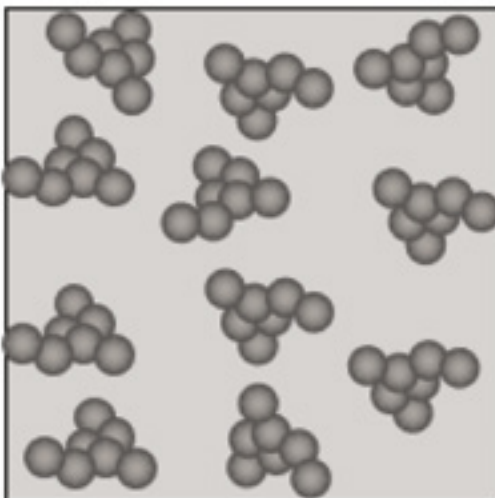
**Poor macro-dispersion,
Poor Conductivity**



**Poor micro-dispersion,
Good Conductivity**



**Good micro-dispersion,
Good Conductivity**



**Excellent micro-dispersion,
Poor Conductivity**

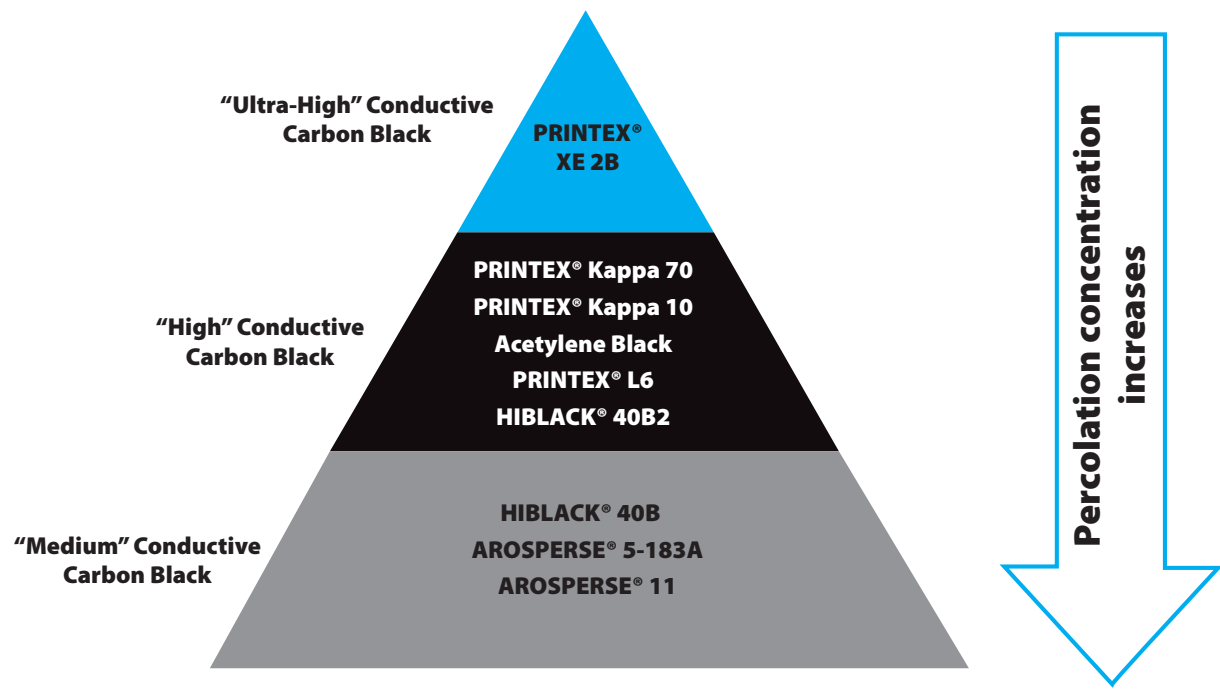
Carbon Black Selection for Conductive Compounds

Orion acetylene black and newly introduced PRINTEX® Kappa 70 showed an excellent balance of conductivity and impact retention within the high shear – 15/15 and lower shear 15/7 rotor sets used in the FARREL POMINI compounding trials. Most ESD applications can be enabled with these Orion conductive carbon blacks. As mentioned in the introduction - in future, thermoplastic conductive compounds will need to meet performance expectations in EMI/RFI and ESD applications. Key criteria include:

- Carbon black selection – does the carbon black selected allow minimum black dosage to realize resistivity and mechanical properties?
- Does the compounding operation allow for just enough black dispersion to minimize mechanical property loss and realize the resistivity target?
- Conductive black compounds generally require >20 percent dosage. Does the price of the carbon black fit the price and performance of your customers' applications?

These questions can be considered in this Figure 8 – within the broader range of Orion conductive carbon blacks.

Figure 8
Conductive Carbon Black Selection



Acknowledgements

The technical and lab staff at FARREL POMINI's Ansonia, CT were instrumental in preparing conductive compounds and reviewing machine and applications data. Within Orion, lab staff at the Kalscheuren, Germany Innovation Lab provided extensive applications testing and interpretation of results.

As mentioned, conductive compound resistivity targets accounts for a large part of carbon black selection:

- EMI/RFI – ultra high conductivity – very low resistivity $<10^2$ ohm cm – PRINTEX® XE2B imparts target resistivity at about 10 to 15 weight percent
- ESD – high conductivity – low resistivity 10^3 to 10^9 ohm cm the broadest end use for conductive carbon blacks (outside of wire and cable) requires 15 to 30 weight percent to hit the resistivity target. Conductive carbon black options can be drawn from Orion high and medium conductive blacks shown in Figure 8.
- Antistat – typically, permanent or non-permanent additives, rather than carbon black, are compounded to achieve $\geq 10^{10}$ ohm cm

Within EMI/RFI end uses PRINTEX® XE2B conductive black enables the best path to desired electric and mechanical properties. Although ESD applications allow selection of a broader range of carbon blacks, the results presented in this Technical Bulletin and drawn from earlier Orion conductive carbon black lab evaluations, Kappa 70 conductive black offers the best balance of lower dosage to stable resistivity and impact property retention.



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