Novel Conductive Blacks for Electrostatic Discharge (ESD) Applications

John Accorsi and Sandeep Bhatt
Cabot Corporation
Billerica, Massachusetts

ABSTRACT

Traditional carbon blacks can impart conductivity to plastic resins but often result in loss of physical properties. The complex interaction between the dispersed carbon black particles and the polymeric phase(s) has been investigated. The understanding of this interaction in the light of the competing mechanical properties – impact strength resistance and stiffness - has spurred the development of novel conductive blacks. The purpose of this paper is to introduce these novel conductive blacks (NCB*: see footnote at the end of this paper), which eliminate this traditional tradeoff and are especially useful in formulating conductive plastic compounds for Electrostatic Discharge (ESD) applications.

INTRODUCTION

Conductive plastic substrates have become increasingly important components of new sophisticated technologies in electronic, medical, communication, military, and other markets. Their functions range from preventing interference with radio and TV communication signals to protecting electronic devices from harmful effects of electromagnetic radiation and electrostatic charge accumulation.

At the end of the 1970s, considerable advances took place in the electronics industry and electronics grew in demand. Since electronic parts are subject to degradation when in contact with static electricity, demand also increased for conductive thermoplastic compounds for handling and packaging.

Carbon black has been used for many years as a conductive additive in plastic compounds. Although the quality of these blacks has improved significantly in terms of chemical and physical cleanliness, the dispersability of traditional conductive blacks has remained a challenge for formulators and processors.

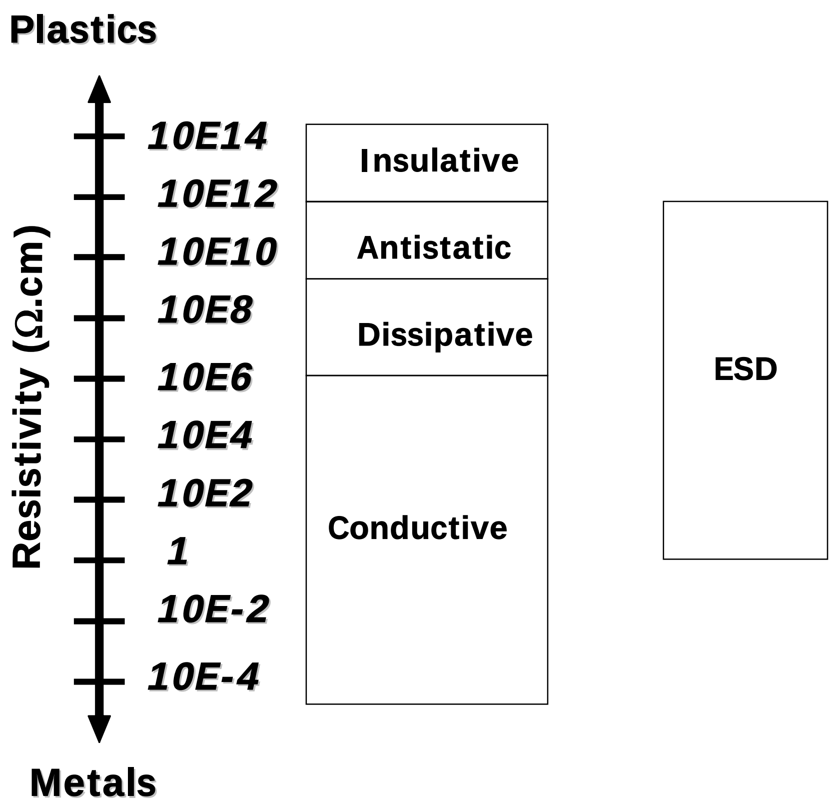
ELECTROSTATIC DISCHARGE PHENOMENON

Static electricity is a natural phenomenon. Everyday actions such as walking across a nylon carpet and then touching a doorknob can produce a shock.

For the electronics industry, Electrostatic Discharge or ESD is more than a nuisance, it is a serious problem. Delicate electronic components are easily damaged by static discharge and the resulting faults in assembled equipment can be costly. The solution is to conduct the static charge slowly and harmlessly to earth.

Static charges can also build up on the surface of fuel pump hoses, on polypropylene bags or boxes containing explosive materials such as gun powder as well as in ducts used in confined spaces, such as in mines and tunnels. One spark can cause devastating damage.

Most natural thermoplastic resins are normally electrical insulators. When combined with carefully designed formulations of conductive blacks, these same resins can change their electrical characteristics from insulating to conductive (see graph below).



MARKET SEGMENTATION

The ESD market can be segmented as depicted below. Each sub-segment is discrete in its performance requirements in relation to the carbon black and its compound.

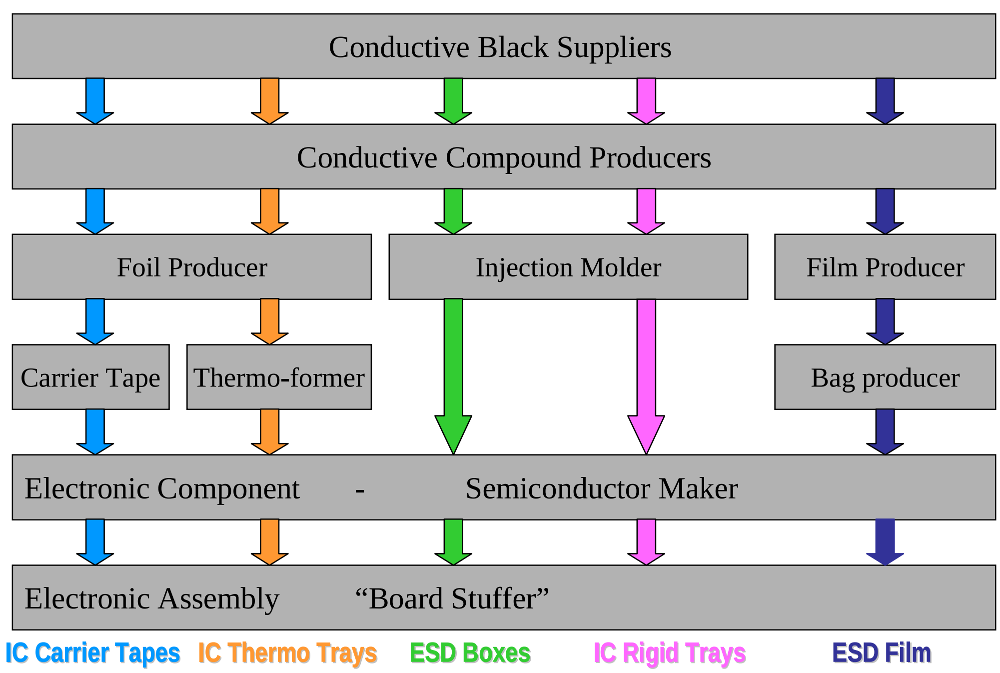
Segment	Sub-segment
Electrical and Electronics	IC Carrier Tapes ESD Films IC Thermoformed Trays ESD Corrugated Boards IC Rigid Trays ESD Boxes
Safety	Containers Fiber/Slit Tape Conveying (Pipes, etc.)
Business Machines	

VALUE CHAIN

The following value chain represents how conductive blacks cascade downstream into the fabrication of conductive plastic parts. The value chain for the conductive plastics packaging market is composed of six (6) levels:

1. Carbon black suppliers
2. Conductive plastics compound producers
3. Semi-finished plastics package producers (also called the converter level)
4. Finished plastics package producers
5. Electronic component manufacturers
6. Electronic assembler (also called the board stuffer)

Value Chain for ESD Segments



PERFORMANCE MEASURES

The ESD market segments are depicted again in the table below showing the two key performance requirements: Conductivity and Dispersability.

Segment	Sub-segment	Conductivity	Dispersability
Electrical and Electronics	IC Carrier Tapes ESD Films IC Thermoformed Trays ESD Corrugated Boards IC Rigid Trays ESD Boxes	●●●●●● ●●●●●● ●●●● ●●●● ●●●● ●●●	●●●●●● ●●●●●● ●●●● ●●●● ●●● ●●
Safety	Containers Fiber/Slit Tape Conveying (Pipes, etc.)	●●●●●● ●●●● ●●●	●●●● ●●● ●●
Business Machines		●●●●●●●	●●

● = indicates degree of importance of the performance measure

Using Quality Functional Deployment (QFD) methodology, we have identified the specific performance measures for conductive blacks for ESD applications and organized them into performance measures of primary and secondary importance:

PRIMARY PERFORMANCE MEASURES

- Conductivity
- Surface Smoothness
- Stiffness (Flexural Modulus)
- Impact Strength
- Carbon Black Dispersability

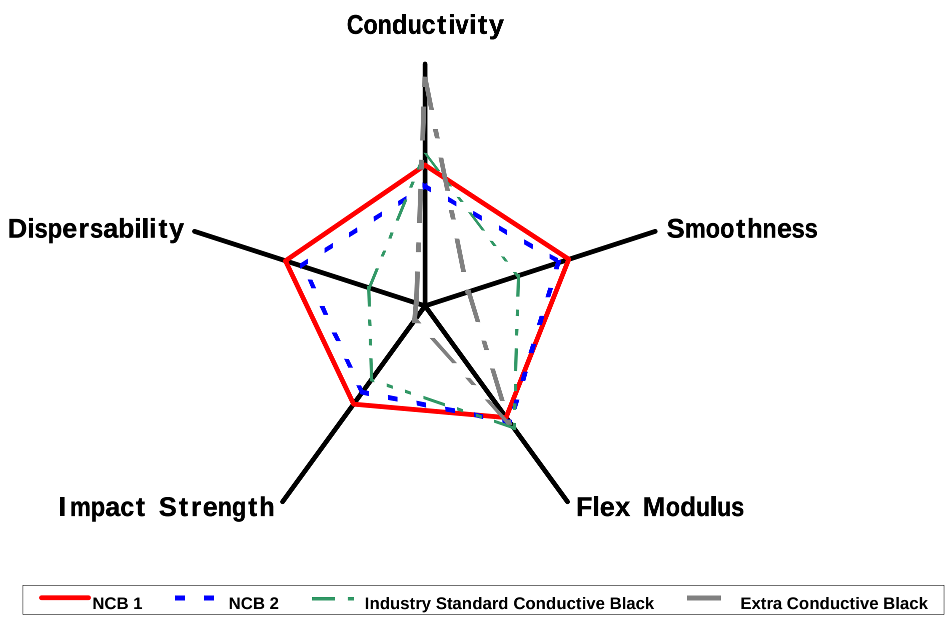
SECONDARY PERFORMANCE MEASURES

- Chemical Cleanliness
- Carbon Black Moisture Pick-up
- Tensile Properties
- Sloughing
- Weld Strength
- Viscosity
- Other...

STAR DIAGRAM

A useful way to compare the relative performance of conductive blacks for ESD applications is to chart the primary performance measures simultaneously in a Star Diagram. The best performance for any given parameter is at the outer perimeter of the graph.

Conductivity is plotted at equal loading to illustrate differences in the carbon blacks. Smoothness, Flexural Modulus and Impact Strength are plotted at equal compound conductivity to show performance at actual adjusted carbon black loading. Dispersability indicates the ease with which the conductive black can de-agglomerate based on the fundamental characteristics of the carbon black and is independent of mixing equipment.



The star diagram demonstrates that the extra conductive black has superior conductivity but is inferior in all other respects. The industry standard carbon black (ISCB) already has a better balance of properties. The novel conductive blacks (NCB's) provide further improvement, hence the best overall performance.

The following describes each of the primary performance measures in more detail.

SAMPLE PREPARATION

For all the experiments conducted for this work, mixing of the compounds in polypropylene copolymer and polystyrene was carried out on a Buss Kneader (PR46). These compounds were made under standard laboratory conditions.

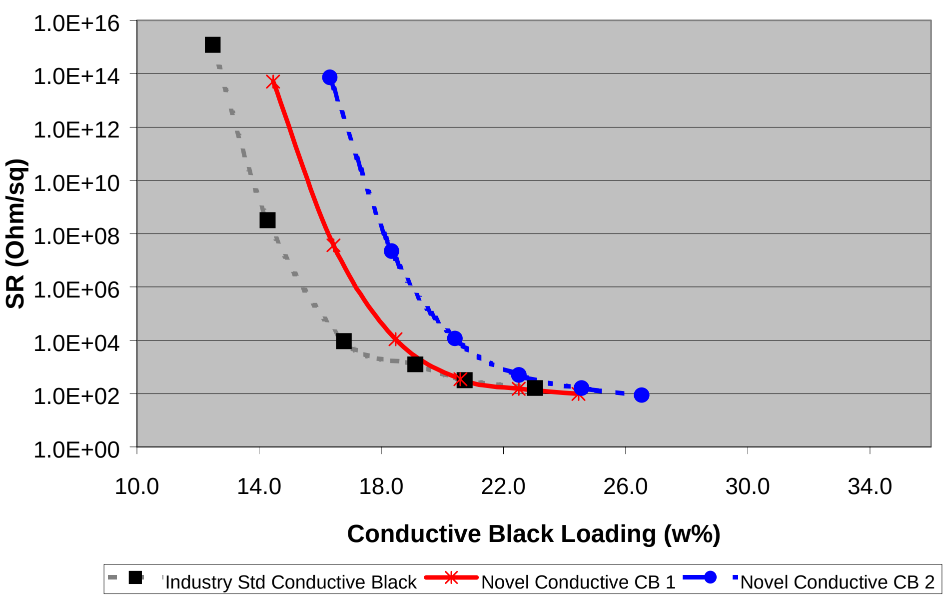
CONDUCTIVITY

Conductivity is measured by the surface resistivity (SR) of the conductive compounds using the four point contact method. A better conductivity performance for a particular conductive black can allow the compound formulator to use a comparatively lower loading to achieve the minimum required surface resistivity for the application.

Conductivity is dependent on:

- the polymer matrix
- the type of conductive black
- the conductive black concentration
- the dispersion quality

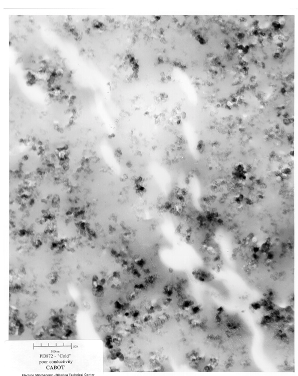
Typical Percolation Curve for Conductive Blacks



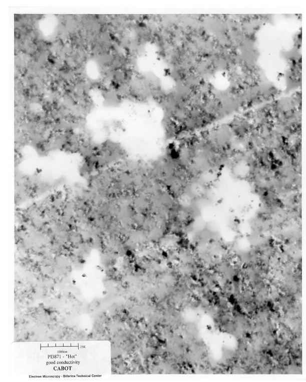
The percolation curves above show that for a given surface resistivity, the loading of ISCB will be lower than the loading of NCB 1, itself lower than the loading of NCB 2. The relative loading differences stay the same when using these novel blacks in various polymer systems at equivalent conductivity.

The mechanism by which carbon black reduces volume resistivity in a polymer is as follows. In the mixing process carbon black is de-agglomerated to form a network of fine conductive particles throughout the matrix, providing a conductive path for electron transfer.

Poor Dispersion
(no networking)



Good Dispersion
(network formed)

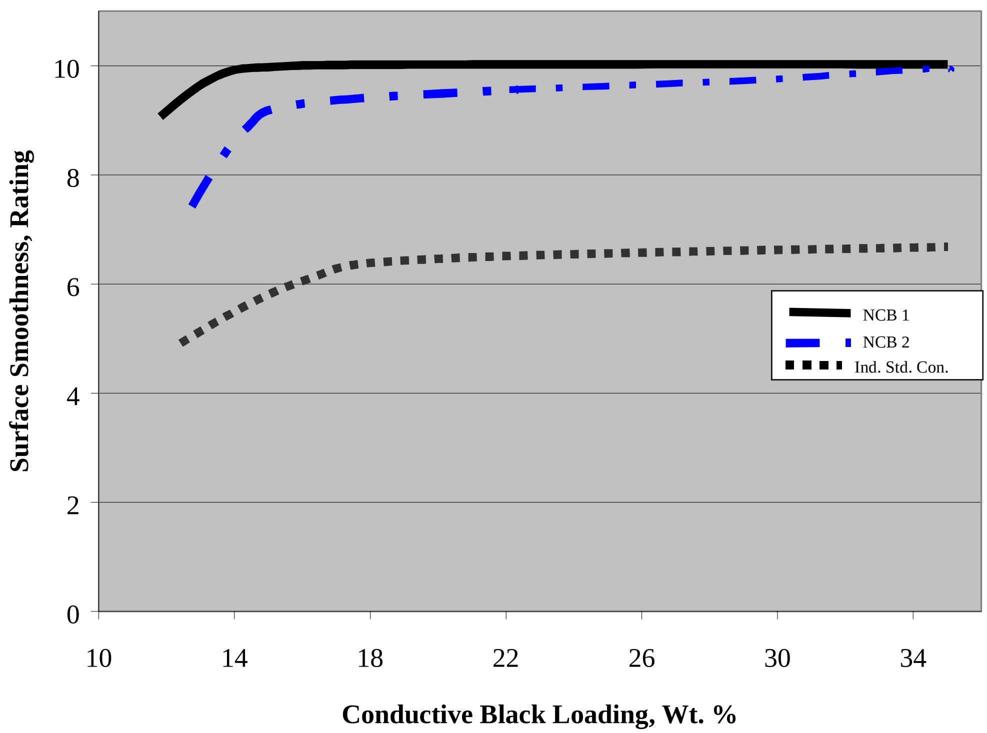


The photomicrographs above illustrate the effect of dispersion on conductivity. The poor dispersion does not allow the network of the conductive particles to form, which consequently leads to higher resistivity of the compounds. The good dispersion creates a network of the conductive particles which allows the electrons to pass easily and consequently enhances conductivity.

SURFACE SMOOTHNESS

The surface smoothness is a measure of surface defects that appear on an extruded tape under tightly controlled conditions. Computer aided image analysis provides accurate measurement and ensures reproducibility. Surface smoothness is dependent on:

- the conductive black concentration
- the type of conductive black
- the polymer matrix
- the mixing technology



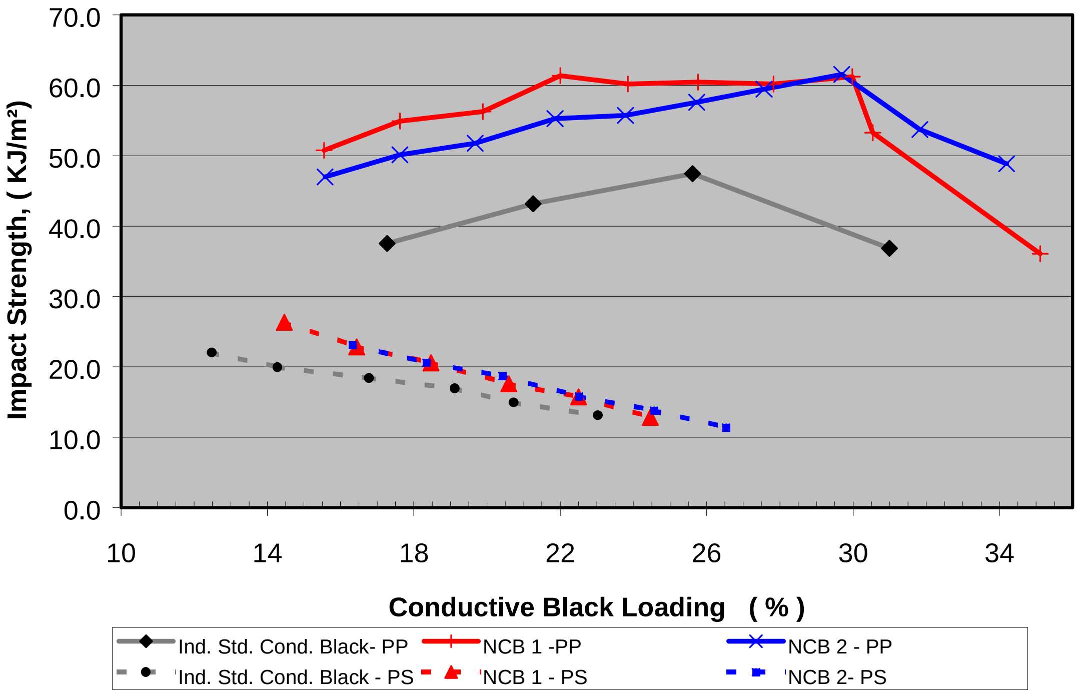
The surface smoothness, which can be achieved with NCB 1, is excellent. NCB 2 shows a slightly lower level of surface smoothness but is significantly better than ISCB. This smoothness measurement is based on the rating system developed by Cabot, with higher rating representing the smoother compounds.

IMPACT STRENGTH RESISTANCE

The impact strength resistance is a measure of the total energy a plastic part can absorb before it breaks when a sudden impact stress is applied.

The break can happen before a deformation has taken place (also called brittle break) or after the part has deformed (also called ductile break).

The impact strength resistance is dependent on:
- the conductive black concentration
- the type of conductive black
- the polymer matrix
- the dispersion quality
- the mixing technology



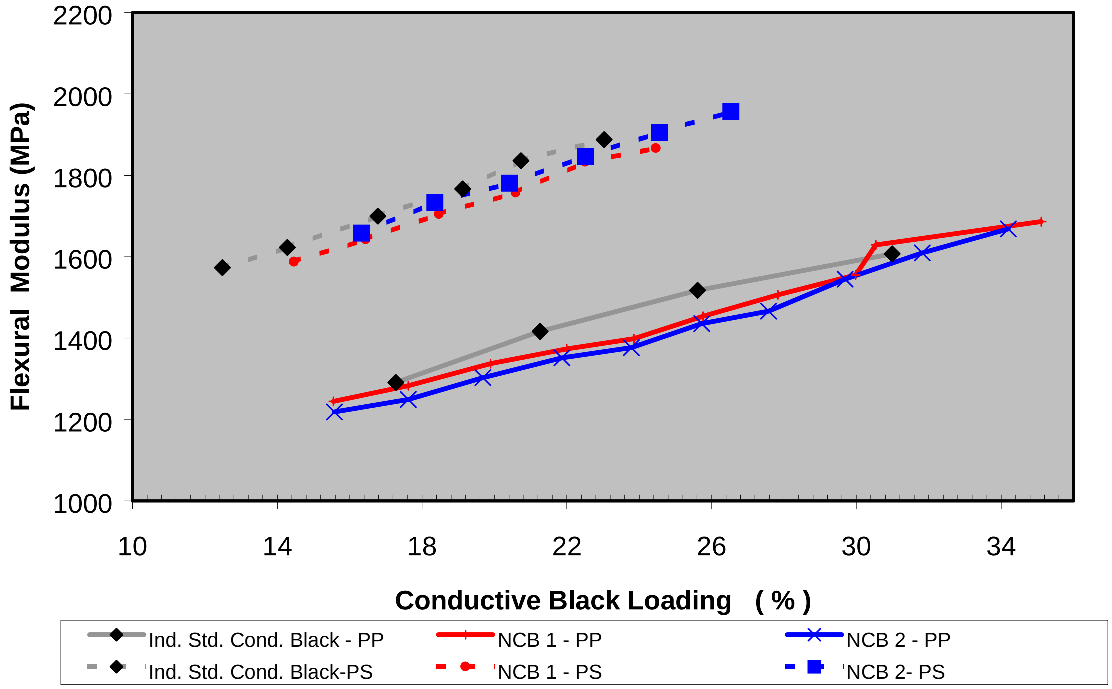
As shown in the graph above, NCB's provide superior impact strength as compared to the ISCB.

STIFFNESS (Flexural Modulus)

The stiffness (flexural modulus) of a plastic part is a measure of its resistance to deformation when increasing stress is gradually applied. The increase in the loading of a plastic part with fine carbon black particles leads to an increase in stiffness. While a good level of stiffness is often desired, it always comes at the expense of ductility or impact strength.

The stiffness is dependent on:

- the conductive black concentration
- the type of conductive black
- the polymer matrix

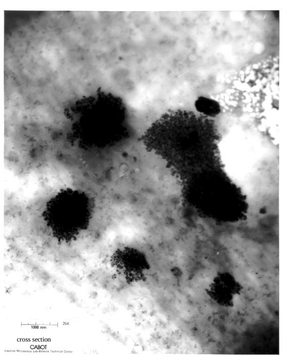


NCB 1 and NCB 2 provide similar levels of flexural modulus to the ISCB as shown in the graph above. The compounds formulated with NCB's have superior impact strength while maintaining similar stiffness compared to the compounds made with ISCB.

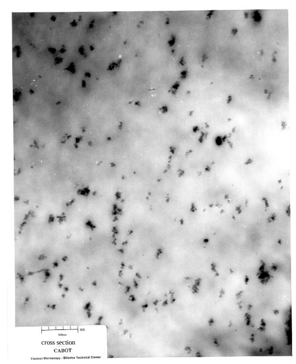
DISPERSABILITY

Conductive black dispersability indicates the ease in which the conductive blacks can be wetted with the resin and subsequently de-agglomerated. This performance measure is dependent primarily on the fundamental characteristics of the conductive black. Considering the physics of small-scale particles, it represents the Van der Waals attractive force one needs to overcome to separate the agglomerates into discrete carbon black aggregates. This measure is independent of the polymeric system used to disperse the black pigment. It also is an indicator of the relative yields that can be achieved on the compounding equipment with the different conductive fillers.

Poor Dispersability
(partial de-agglomeration)



Excellent Dispersability
(full de-agglomeration)

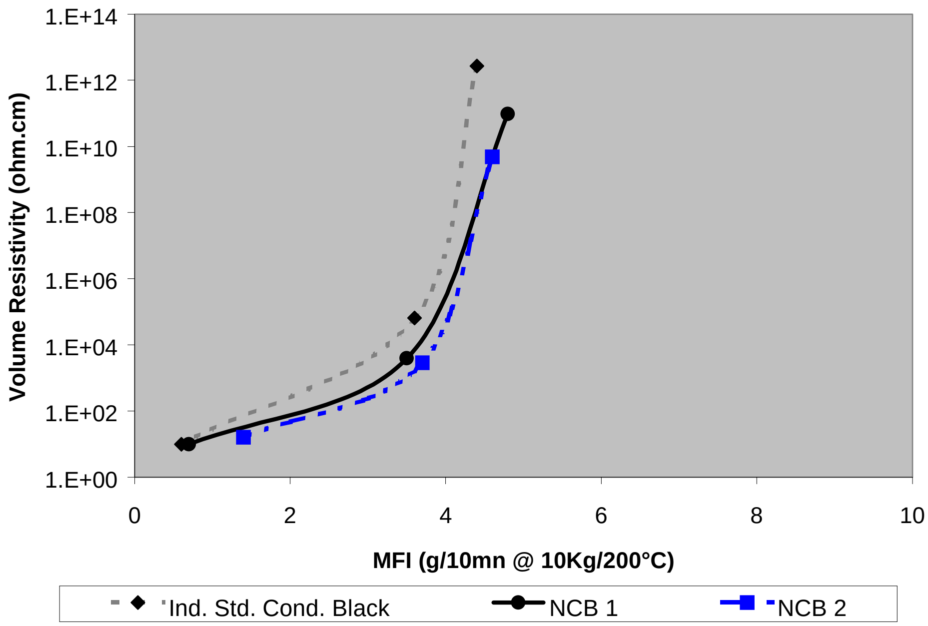


The photomicrographs above illustrate how dispersability of the conductive black affects the de-agglomeration and polymer wetting. It is easier to achieve full de-agglomeration and wetting with the novel conductive blacks.

VISCOSITY

All the conductive blacks in the study provide similar viscosity at the equivalent levels of volume resistivity as shown in the graph below. The NCB's perform slightly better than the ISCB, i.e. MFI is higher at equivalent conductivity.

Volume Resistivity Vs Melt Flow Index (MFI) in Polystyrene



SUMMARY

Novel conductive blacks have been developed which can provide an improved balance of conflicting mechanical properties – impact strength resistance and stiffness, while maintaining excellent conductivity. Formulators of plastic compounds used for ESD applications will benefit from the subsequent improvement in physical properties, e.g. smoothness, flexural modulus and impact strength.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the guidance and assistance of their colleagues at Cabot Corporation, including Filip Smeets, Alain Thielen, Emma Wickens and Baudouin Valange.

*** N.B.:**

In this paper, we have replaced VULCAN® XC605 by NCB1, VULCAN XC305 by NCB2, and VULCAN XC72 by Industry Standard carbon black.