Materials & Coatings

Conductive Carbon Nanotube Inks for Use with Desktop Inkjet Printing Technology

A mixture of carbon nanotubes and silver or gold nanoparticles could be applied by inkjet printing to flexible substrates.

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Inkjet printing is a common commercial process. In addition to the familiar use in printing documents from computers, it is also used in some industrial applications. For example, wire manufacturers are required by law to print the wire type, gauge, and safety information on the exterior of each foot of manufactured wire, and this is typically done with inkjet or laser printers.

The goal of this work was the creation of conductive inks that can be applied to a wire or flexible substrates via inkjet printing methods. The use of inkjet printing technology to print conductive inks has been in testing for several years. While researchers have been able to get the printing system to mechanically work, the application of conductive inks on substrates has not consistently produced adequate low resistances in the kilohm range.

Conductive materials can be applied using a printer in single or multiple passes onto a substrate including textiles, polymer films, and paper. The conductive materials are composed of electrical conductors such as carbon nanotubes (including functionalized carbon nanotubes and metal-coated carbon nanotubes); graphene, a polycyclic aromatic hydrocarbon (e.g., pentacene and bisperipentacene); metal nanoparticles; inherently conductive polymers (ICP); and combinations thereof. Once the conductive materials are applied, the materials are dried and sintered to form adherent conductive materials on the substrate. For certain formulations, increased conductivity can be achieved by printing on substrates supported by low levels of magnetic field alignment. The adherent conductive materials can be used in applications such as damage detection, dust particle removal, smart coating systems, and flexible electronic circuitry.

By applying alternating layers of different electrical conductors to form a layered composite material, a single homogeneous layer can be produced with improved electrical properties. It is believed that patterning alternate layers of different conductors may improve electrical pathways through alignment of the conductors and band gap optimization.

One feature of this innovation is that flexible conductive traces could be accomplished with a conductive ink having a surface resistivity of less than 10 ohms/square. Another result was that a composite material comprising a mixture of carbon nanotubes and metallic nanoparticles could be applied by inkjet printing to flexible substrates, and the resulting applied material was one to two orders of magnitude more conductive than a material made by printing inks containing carbon nanotubes alone.

Enhanced Schapery Theory Software Development for Modeling Failure of Fiber-Reinforced Laminates

This tool captures the physics of the damage and failure mechanisms.

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Progressive damage and failure analysis (PDFA) tools are needed to predict the nonlinear response of advanced fiber-reinforced composite structures. Predictive tools should incorporate the underlying physics of the damage and failure mechanisms observed in the composite, and should utilize as few input parameters as possible.

The purpose of the Enhanced Schapery Theory (EST) was to create a PDFA tool that operates in conjunction with a commercially available finite element (FE) code (Abaqus). The tool captures the physics of the damage and failure mechanisms that result in the nonlinear behavior of the material, and the failure methodology employed yields numerical results that are relatively insensitive to changes in the FE mesh. The EST code is written in Fortran and compiled into a static library that is linked to Abaqus. A Fortran Abaqus UMAT material subroutine is used to facilitate the communication between Abaqus and EST.

A clear distinction between damage and failure is imposed. Damage mechanisms result in pre-peak nonlinearity in the stress strain curve. Four internal state variables (ISVs) are utilized to control the damage and failure degradation. All damage is said to result from matrix microdamage, and a single ISV marks the microdamage evolution as it is used to degrade the transverse and shear moduli of the lamina using a set of experimentally obtainable matrix microdamage functions. Three separate failure ISVs are used to incorporate failure due to fiber breakage, mode I matrix cracking, and mode