1 Introduction
Carbon nanoparticles (CNPs) [1-6] have attracted a great deal of attention in many research fields, due to their special electronic, mechanical, and chemical properties. The applications of CNPs for many industrial and commercial practices are expected to be increased considerably. As these properties make them ideal, CNPs are expected to be useful fillers for improving the properties of polymers. Researchers have taken advantages of CNPs’ conductivity and high aspect ratio to produce conductive plastics with exceedingly low percolation thresholds [1]. There are two challenges in achieving the reinforcing effect of CNPs in nanocomposites; the uniform dispersion of CNPs and a good adhesion between CNPs and the host polymer matrix. Consequently, various methods of chemical functionalization of CNPs and fabrication of CNPs/epoxy composites have been explored.

Electrophoretic deposition (EPD) is an electro-chemical method attracting much interest as a simple and versatile technique for the production of coatings and films consisting of nanoparticles and carbon nanotubes (CNTs) [4-7]. With charged particles dispersed in a suitable suspension, EPD is achieved via motion of them towards an oppositely charged electrode under an applied electric field. A homogeneous and stable deposit on the electrode is formed in this method [8-11]. In this study, CNPs were deposited on carbon fabrics via EPD method, and the deposition characteristics and the improvement of electrical conductivity of CNPs/carbon fabric composites have been investigated.

2 Experimental
2.1 Materials

Thin multi-walled carbon nanotubes (t-MWCNTs) and vapor grown carbon nanofibers (VGCFs) were utilized as nanoparticles, which are dispersed in distilled water suspension for EPD process. The t-MWCNTs were purchased from Hanwha Nanotech in Korea having a commercial brand name of ‘CM-100’ as shown in Fig. 1 (a). The VGCFs were Pyrograf®-III ‘PR-19’ purchased from Applied Science Inc., OH, USA. The microstructure of VGCFs was shown in Fig. 1 (b). The plain woven...
carbon fabrics shown in Fig. 1 (c) (Mitsubishi TR50, 3k) were used as the anodic substrate in EPD process.

2.2 Anodic EPD process

EPD process was carried out under a constant voltages of 60V, time of 10 min, and concentration of 5 mg/cm³ for both t-MWCNTS and VGCFs. The carbon fabric was connected to an anode with a power supply, and copper plate of 0.3-thick was used as a cathode as shown in Fig. 2. After deposition, the deposited carbon fabrics were dried in an oven at 120 °C for 24 hrs.

2.3 Characterization

In order to examine the functional groups on the t-MWCNTS and VGCFs surface, Fourier transform infrared (FTIR) spectra of the untreated and negative charged CNPs were recorded on a JASCO FTIR spectrometer with KBr pellets at a resolution of 4 cm⁻¹.

The surface morphologies of original carbon fibers and deposited carbon fabrics were observed by scanning electron microscope (SEM).

3 Results and Discussion

3.1 Negative Charged CNPs

To obtain pure deposition of t-MWCNTs or VGCFs, anodic EPD process was adopted in this study. Since the negative charged CNPs were needed in this process, they were treated by an acid oxidization. This treatment method was summarized in Fig. 3. The carboxyl groups (-COOH) on the surface of MWCNTs were modified to the form of “-COO⁻” after nitro acid oxidation. These modified MWCNTs were known as negative charged t-MWCNTs. It was confirmed by Fourier transform infrared (FT-IR) spectrometer which is one of the powerful techniques to study surface properties of CNTs [2-3]. The FT-IR spectra of the original and oxidized t-MWCNTs and CNFs in the range of 400-4000 cm⁻¹ are shown in Fig. 4. The bands at 1076, 1540, 1730 and 3440 cm⁻¹, corresponding to vibrations \(\nu(C=O)\), \(\nu(C=O, \ -COO)\), \(\nu(O-H, \ -OH)\), respectively, were all reinforced [12-13]. The oxidized nanoparticles showed carboxylic group (-COOH) vibrations stretching C=O at 1716 cm⁻¹ and C-O at 1162 cm⁻¹[14]. These results directly indicate that the oxidized t-MWCNTs and VGCFs contained more oxygen bearing groups than the original t-MWCNTs and VGCFs.

3.2 Deposition of Carbon Nanoparticles

Surface morphologies of t-MWCNTs- and VGCFs-deposited carbon fabrics are shown in Fig. 5. A t-MWCNTs film was formed on the entire surface of a carbon fabric. Furthermore, the space between two
carbon fibers was fully covered as shown in Fig. 5(a). The deposition of VGCFs was also uniform, and they were clearly observed as shown in Fig. 5(b) because the diameter is ~200 nm. However, small agglomerations could be found in the SEM images. This is an important issue that restricting the applications of nanoparticles. It might act as defects in composites reducing mechanical properties especially.

3.3 Electrical Conductivity

Composite samples were prepared by vacuum assisted resin transfer molding (VARTM) process. Then, a size of 20 mm × 20 mm × 2 mm specimen was manufactured for the electrical conductivity test. The electrical conductivities of the composites were measured in two directions; in the plane direction and in the thickness direction. With the addition of nanoparticles into the composites, the electrical property was improved remarkably. Especially, the through-the-thickness electrical conductivity of the nanocomposites was enhanced more than 50 times as compared to the composites without addition of
nanoparticles as shown in Fig. 6 (a). It indicated that deposited CNPs had the function to connect each layer of carbon fabric in composites. In case of the in plane direction, the results of electrical conductivities of nano composites were about twice of the composite without CNPs.

4 Conclusions

Carbon nanoparticles were deposited on the carbon fabrics via a route of EPD process. Compared to t-MWCNTs, the deposition film of VGCFs was much thicker due to the larger diameter. While compared nano composites with the composite without CNPs, it was found that the electrical conductivity of the nanocomposites increased more than 50 times in the thickness direction, and about 2 times in the plane direction.

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