# A Feasibility Study on CNT- and Graphene-aided Structural Health Monitoring of Wind Turbine Blades

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## ABSTRACT

This paper presents a study on incorporation of hybridized MWCNTS and rGO in fiber-reinforced plastics for structural health monitoring in real time. Carbon nanoparticle that has certain MWCNT to rGO ratio was dispersed in a solvent were uniformly spray-coated on the surfaces of glass fiber fabrics, which were then layed-up and impregnated with an unsaturated polyester resin using vacuum-assisted resin transfer molding(VARTM) to form composite samples. Prior to VARTM process, electrodes were embedded on the sprayed coated glass fiber ply for electrical resistance change monitoring. The composite sample was subjected to cantilever bending and twist test, during which the changes in resistances between various electrode pairs were measured and recorded. Experimental results showed the dependence of resistance change on the deformation. In particular, this research covers hybridized MWCNTS and rGO electrical network on wind turbine blade. Cantilever bending and twist test were demonstrated by simulation program and this paper gives proposal about future application on huge composite part with MWCNT and rGO.

## 1. INTRODUCTION

As many people require huge and cost-efficient structures, CFRP and GFRP application are gradually increased in automobile and aircraft field, SHM is getting importance in composite industry. There have been numerous methodologies on SHM with CNT and Graphene. In this research, we want to apply hybridized nano material CNT and RGO structure in GFRP for SHM. Focus on the electrical network between CNT and reduced Graphene Oxide by using piezoresistivity and analyze effect of hybridized nanomaterial ratio to composite deformation response sensitivity.

## 2. EXPERIMENTAL

### 2.1. Materials

Thermal CVD-grown MWCNTs (CM-100) with a purity rating of > 95%, inner and outer diameter ranges of 5-10 nm and 60-100 nm, respectively, and an average length of 100 μm were purchased from Hanwha Chemical (Incheon, Korea). Reduced Graphene Oxide(GO-V30-100) with lateral size of≥7 μm and thickness of<5nm were purchased from Standard Graphene. Plain-woven glass fiber textiles were used as the reinforcement for scaled-down wind turbine blades. Plain-woven glass fiber textiles were purchased by JMC (Gyeongju, Korea). The unsaturated polyester resin (Epovia RF-1001MV) which was used as matrix were supplied by Jet Korea, curing agent from Arkema, and catalyst from Jet Korea respectively.

### 2.2. Composite turbine blade fabrication

A total weight 0.1g of MWCNT and reduced Graphene Oxide(rGO) were dispersed in methanol 50ml by sonication. The weight ratio of MWCNT and rGO was changed to 10:0, 8:2, 5:5, 2:8, 0:10 to understand the network effect between MWCNT and rGO in the composite wind turbine blade. A 80 mm X 480 mm fiber textile was coated on one side of it by spraying the MWCNT suspension using an air brush. There are two molds(upper and lower) that was scaled down by 4 factor. Three glass fiber textiles which were trimmed 80mm X 480mm were stacked on each mold. On the upper blade mold, third layer that are stacked at the top was MWCNT- rGO sprayed coated glass fiber. After embedding of electrodes, the unsaturated vinyl ester resin was infused into the stacked textiles by vacuum-assisted resin transfer molding (VARTM). After resin curing, demold two composite blade parts, blade parts were trimmed and bonded with an epoxy adhesive.

### 2.3. Electromechanical test

The composite mini wind blades were subjected to 5 cycles of cantilever test by using an Instron 5982 universal materials testing system, and the resistances between all electrode pairs were measured simultaneously using a Keithley 2002 multimeter and 7001/7012-S switching system. And also composite mini wind blades were subjected to 5cycles of twist test by using hand-made twist test equipment. It was consisted of Aduino Uno R3 board(CH340 Uno R3), CNC router single axis 3A TB6560 stepper motor drivers for axis control and stepping motor(NEMA17). The resistances between all possible pairs of adjacent electrodes were measured real-time *in situ.*

## 3. RESULTS AND DISCUSSION

### 3.1. Electromechanical behavior of blade under flexure

Figure 1(a),(b),(c),(d),(e) show the resistance change ratio in the all cases of one domain section in each blade MWCNT-to-rGO ratio 10:0,8:2,5:5,2:8,0:10. Except pure graphene blade, clear five cycle trends were observed in four different kind of ratio of hybridized blade. The highest resistance change ratio was observed in 2~3 and 3~4 sections. These results show that 2~3 and 3~4 regions have high strain against cantilever bending. Table 1 shows first cycle resistance change ratio during value increasing in each different ratio of hybridized blade. 2:8 MWCNT-to-rGO ratio was observed high slope among four different blade. It means that it was the most sensitive in deformation change. When the RGO contents in the composite blade was increased, sensitivity also increased in same strain. The reason is that pure MWCNT blade constructs the strong point network because it was tightly packed, tangled each other. Otherwise in pure rGO, 2 dimensional nanomaterial, blade, line and area network are dominant. That's why rGO network is comparatively easy to separate each other. Line and area network has large contact area. So rGO network break cause more big effect on the total network than point network breakage like MWCNT network. But in experimental result, pure rGO blade didn't show the highest sensitivity in deformation. This phenomenon might be investigated due to purity of Graphene or network reversibility. Little MWCNT help rGO return electrical network with reinforcing the network connection. Until now for these reasons, 2:8 ratio of MWCNT to rGO shows high sensitivity under the same cantilever strain.

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### 3.2. Electromechanical behavior of blade under torsion

As shown figure 2, in all cases of hybridized blade twist test except pure rGO blade, two peak point were shown during one cyclic twist test. First peak indicates the 10 degrees twist to counter clockwise direction, second peak point indicates the 8 degrees twist to clockwise direction. The ratio of MWCNT-to-rGO 2:8 blade shows the largest resistance change ratio. So as shown table 2, 2:8 MWCNT-to-rGO ratio was observed high slope among four different blade. It means that it was the most sensitive in angle deformation change.

## 4. CONCLUSIONS

Scaled-down wind turbine blade consisting of vinyl ester resin, glass fiber fabrics and spray-coated MWCNT layers, integrated with electrodes, were prepared using VARTM. Hybridized turbine blades were fabricated with changing the ratio of MWCNT-to-rGO 10:0,8:2,5:5,2:8 and 0:10. In cantilever bending test, the distributed MWCNT and rGO network showed clear positive cyclic resistance change ratio in cantilever deformation. In all kinds of hybridized wind turbine blades except pure rGO blade, 2~3 and 3~4 sections showed the largest resistance change, it leads to large strain at these sections. In torsion twist test, hybridized network also showed clear positive cyclic resistance change ratio in angle of twist change. The concentration of rGO was proportional to sensitivity. But pure rGO blade cannot be monitored in real time due to impurity and irreversible network. So the ratio of MWCNT-to-rGO 2:8 showed highest sensitivity on strain due to the large number of point, line and area network. In a huge structure including aircraft, automotive and civil structures, firstly through the simulation program check the most susceptible to failure part in structure, and then selectively coat on that part with optimized electrode location. While minimizing the material and processing cost like this, efficient structural health monitoring with high sensitivity can be possible in real time.

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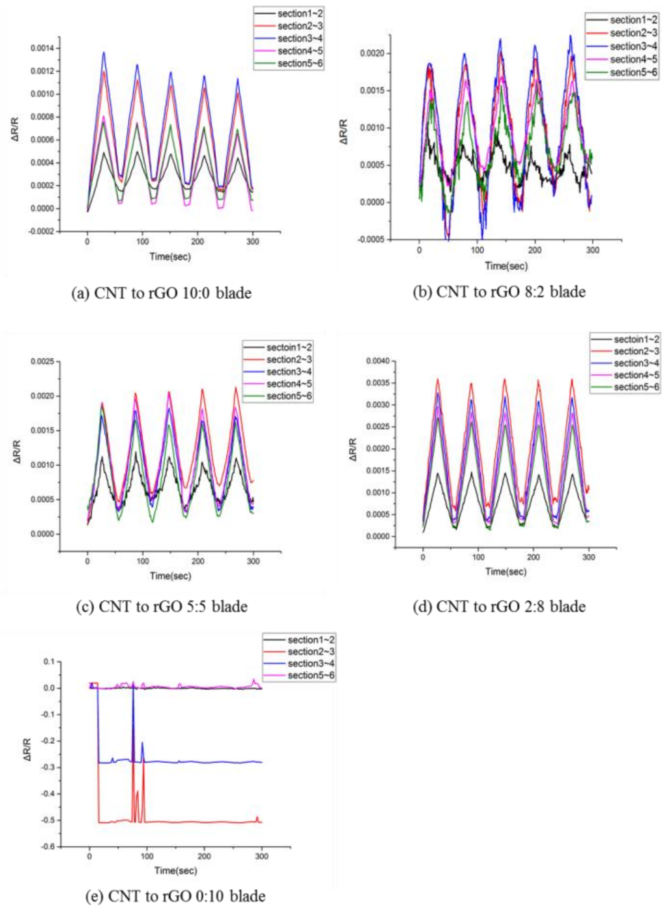
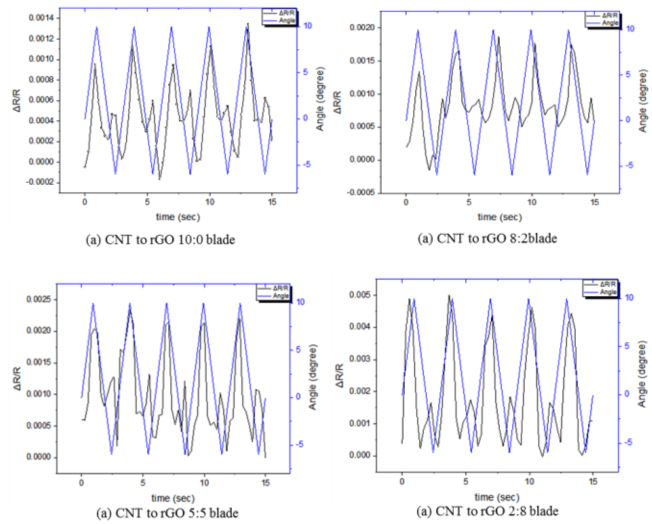



(a) CNT to rGO 10:0 blade
(b) CNT to rGO 8:2 blade
(c) CNT to rGO 5:5 blade
(d) CNT to rGO 2:8 blade
(e) CNT to rGO 0:10 blade

**Figure 1** Normalized resistance change in different ratio of MWCNT- to-rGO blade

**Table 1** Slope of each ratio blade in cantilever bending

| Ratio of CNT to rGO | Slope |
|---|---|
| 10:0 | 0.0000807 |
| 8:2 | 0.0001034 |
| 5:5 | 0.0001217 |
| 2:8 | 0.0002086 |




(a) CNT to rGO 10:0 blade
(a) CNT to rGO 8:2blade
(a) CNT to rGO 5:5 blade
(a) CNT to rGO 2:8 blade

**Figure 2** Normalized resistance change in different ratio of MWCNT-to-rGO blade

**Table 2** Slope of each ratio blade in twist

| Ratio of CNT to rGO | Slope |
|---|---|
| 10:0 | 0.00003381 |
| 8:2 | 0.0003932 |
| 5:5 | 0.000544 |
| 2:8 | 0.0018183 |

## BIOGRAPHIES

**In Yong Lee** is a graduate student in UNIST, Ulsan, Republic of Korea. Research field is the electromechanical behavior of carbon based material investigating piezoresistivity on FRP. and now he is in the 2th year of M.S.-Ph.D. combined program.

**Young-Bin Park** is an Associate Professor of Mechanical Engineering at UNIST. His research interests are in the field of advanced composites and nanocomposites for smart, functional applications. In particular, his research focus is on the application of high-performance carbon-based materials, especially graphene, carbon nanotubes and carbon fibers, to multifunctional composites and structures. More recently, he has expanded his scope of research into novel technologies for rapid, affordable manufacturing of fiber-reinforced composites, particularly targeted for automotive industry. Professor Park received his B.S. and M.S. from Seoul National University in 1995 and 1997, respectively, and Ph.D. from Georgia Tech in 2003.