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# Design of a structural power composite using graphene oxide as a dielectric material layer

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ABSTRACT

This paper aims at introducing a new type of multifunctional polymer-based composites, which partially act as a primary structural component as well as an energy storage device, potentially for any flying object, like unmanned air vehicles (UAV), and automotive applications. In this study, it was found that a continuous carbon fibre reinforced epoxy composite (CFRP) inserted with a layer of graphene oxide (GO) paper, which is 4 μm in thickness, exhibited a better capacitance (17.13 $\mu F/m^2$) as compared with the one fabricated by using a layer of regular printing paper with the thickness of 0.1 mm as a dielectric separator (2.18 $\mu F/m^2$). The printing specimens were used in this study because of their highest specific capacitance reported in the previous studies. Through the experiments, it is evident that the GO paper is an excellent candidate as dielectric separator for structural dielectric capacitors as well as demonstrates its potential for the development of multifunctional energy storage device embedded in a carbon-based structure.



## 1. Introduction

Multifunctional composite materials, which are able to perform more than one function simultaneously, have attracted a great deal of attention due to the significant weight and volume reduction for engineering designs. With the integration of energy storage function, fibre reinforced composites (FRP) can serve as batteries, capacitors or supercapacitors that can provide structural supports at the same time. They are considered as structural power composites (SPCs). The attraction of using FRP in SPCs is arisen from their unique combination of good electrical properties, corrosion resistance and thermal stability [1,2].

Structural dielectric capacitors using carbon fibre reinforced composites (CFRP) electrodes with different paper-based dielectric interlayers were firstly demonstrated by Luo and Chung [3]. Later, the specific capacitances of structural dielectric capacitors with various polymer films [4] and glass fibre reinforced composite (GFRP) dielectrics [5] have also been reported between 0.206 $\mu F/m^2$ and 1.86 $\mu F/m^2$. These results showed that those dielectric materals used in the existing structural dielectric capacitors have low dielectric constants, resulting in low capacitances. Therefore, other dielectric materials with good dielectric and mechanical properties should be proposed to develop new structural dielectric capacitors with the aim to enhance their capacitances.

In this study, graphene oxide (GO) paper was selected as a new dielectric material of structural dielectric capacitors. The electrical conductivity of GO varies between $5 \times 10^{-6}\ Sm^{-1}$ and $4 \times 10^{-3}\ Sm^{-1}$ based on its oxidation degree and working environment, indicating that GO behaves like an insulator [6,7]. In addition, GO paper has been reported to have high dielectric constants, up to the order of $10^4$, accounting for high capacitance [6,7]. Besides, GO papers exhibits high dielectric strengths (EBD), reported as 150 kV/mm [8], and it is a promising layered material for lightweight structural applications due to its outstanding mechanical properties [9]. In this work, the potential of using GO paper as dielectric material of structural dielectric capacitors is identified through the comparison on energy storage performance between new and existing structural dielectric capacitors.

## 2. Experimental methods

### 2.1. Sample fabrication

The single layer structural dielectric capacitors, as shown in Fig. 1, were fabricated by stacking two carbon fabrics (Toray Carbon Fibers America Inc.), separated by a single layer of dielectric

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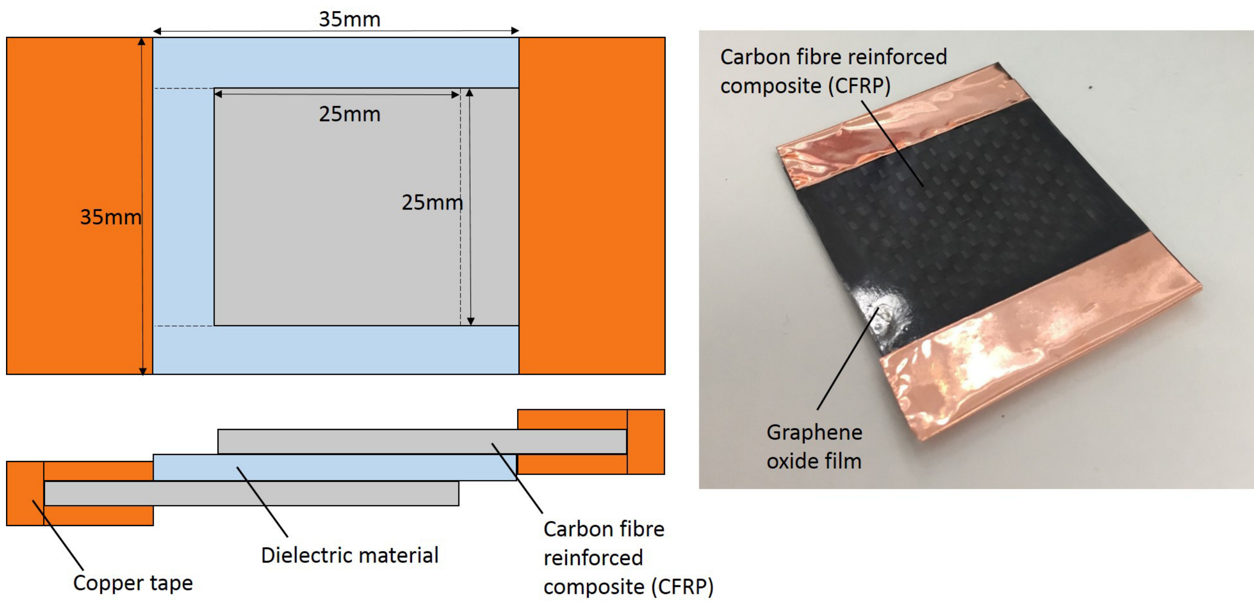


**Fig. 1.** Schematic configuration of structural dielectric capacitors (left) and specimen made from CFRP electrodes and GO film dielectric (right).

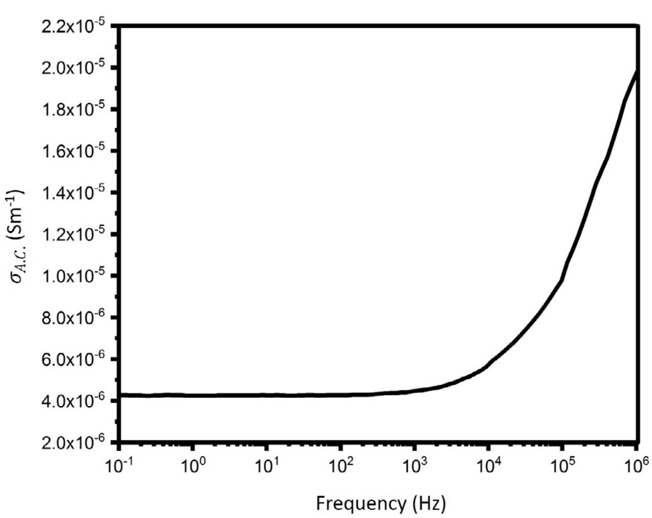


**Fig. 2.** A.C. conductivity with varying frequency at 22 °C of GO paper.

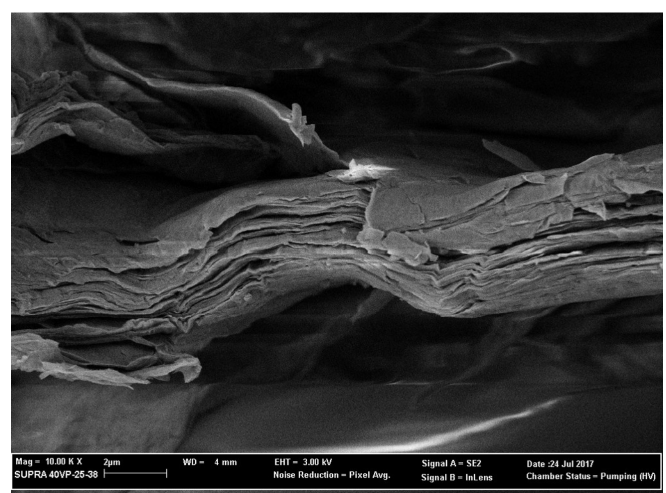


**Fig. 3.** Microstructure of GO paper observed by using SEM.

through the combined process of hand lay-up and lamination. The epoxy matrix (West System 105/206) with a mixing ratio of 5:1 (resin/hardener) was used to form composites. Two kinds of dielectric materials, regular printing papers and GO papers, were employed. The GO papers were fabricated through the vacuum filtration by using GO solution (SupraG, Australia) and their thicknesses were carefully measured as 4.0 μm by using atomic force microscope (AFM). The laminated specimens were cured at 22 °C for 24 h under vacuum condition with the purpose of removing air bubbles inside specimens, resulting in high-quality composites.

### 2.2. Sample characterization

Impedance measurements were carried out on GO papers by using the electrochemical impedance spectroscopy (EIS) in order to determine their conductivity before the sample fabrication. The impedance was recorded under various applied frequencies, ranging from 0.1 Hz to 1 MHz, at 22 °C. Moreover, the microstructure of GO papers was investigated by performing scanning electron microscopy (SEM).

Capacitance measurements were conducted on 12 specimens, six for each type of dielectric, by using precise multimeter, Fluke 87 V. From Fig. 1, it shows that the effective area of specimen was 25 mm × 25 mm. To prevent the edge effect and contact between electrodes, insulating materials were cut with an excess width of at least 5 mm around electrodes [4].The nominal thickness of cured specimens was found between 0.58 mm and 0.76 mm, depending on the dielectrics used. For a better electrical connection, copper tapes were applied at the end of both bottom and top surfaces of specimens.

Dielectric strength (EBD) tests were performed on specimens after capacitance measurements, according to ASTM 3755-95 standard [10]. Each specimen was subjected to an increasing applied voltage with rate of 100 V/s by using a high-voltage supply (Matsusada Precision Inc., Japan). The voltage across the specimen was monitored by using Fluke 87 V multimeter. Voltage was applied until a sudden drop in the voltage across the specimen.