Structural health monitoring for wind turbine blades via graphene self-sensing adhesive layer joining fibre-reinforced plastics

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Project period: Jan 2020 – Sep 2021

Executive summary

This joined project explores the manufacturing process of electrically conductive graphene nanoplatelets (GNPs) reinforced adhesive for fibre reinforced plastics (FRP) composite and develops a wireless structural health monitoring system. Infusion epoxy was chosen as the structural adhesive in this project due to the low viscosity and bonding capacity. Various GNPs dispersion processes were investigated, and percolation threshold was identified at 0.75wt%. Arduino and low power Bluetooth were chosen as the microcontroller and wireless transceiver due to their low energy consumption and modest transmission distance. We have chosen single-lapped joint FRP composite laminate to demonstrate the performance of the system.

Program of work

This project aims to demonstrate the feasibility of using self-sensory GNPs reinforced adhesive for composite-composite joint. Three objectives have been achieved during the project period:

Objective 1 – Manufacturing of GNPs reinforced adhesive

GNPs reinforced adhesive was prepared by a solvent-free method, which combines mechanical mixing and ultrasonic bath. Different GNPs loading (0.25 wt% to 5 wt%) were tested to identify the percolation threshold [1]. Two sizes of GNPs, namely $2\ \mu m$ and $25\ \mu m$, were tested. Then. unreinforced and GNPs reinforced adhesives were cast in silicone mould having dog-bone shape cavities. The effects of the GNPs loading and distribution on tensile properties of adhesive were investigated according to ASTM D638.

Objective 2 – Wireless structural health monitoring system

The wireless system is constructed by five core modules (Fig.1a): 1) microcontroller: Arduino. Arduino is an open-source hardware and software platform, which supplies an onboard 10-bit analogue-digital converter (ADC), whose resolution is insufficient to extract the small change of electric signal in this case. 2) ADC: ADS1256. ADS1256 is an extremely low noise 24-bit high resolution ADC, which can detect up to 30k samples per second (SPS). 3) Wheatstone bridge. A potentiometer is integrated inside the bridge so that it can adapt to various measurement range. 4) wireless transceiver: HC05. HC05 is a Bluetooth transceiver which talks to Arduino via SPI (serial spherical interface). 5) Power supply. The system is powered by a 9V battery.

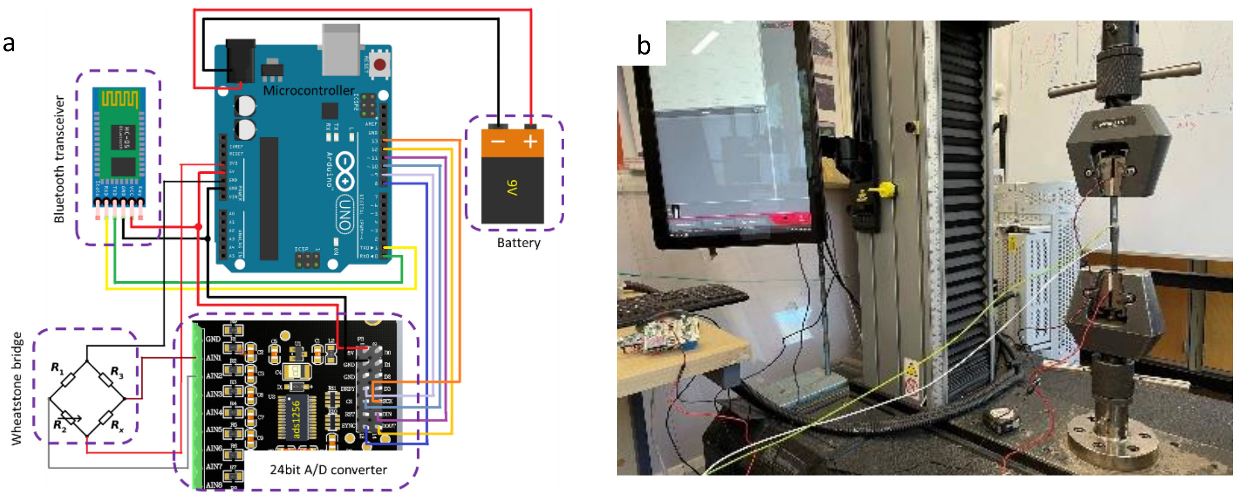

Fig.1 The diagram and wiring of the system (a), tensile test setup (b)

Objective 3 – Demonstration of in-situ monitoring of composite-composite Lap-joint

To demonstrate the performance of the system, single-lapped joint FRP composite specimens were prepared. Both carbon fibre and glass fibre were investigated. Silver epoxy was used to connect the GNPs reinforced adhesive to the monitoring system. Tensile test was carried out on an Instron Universal machine following ASTM D3165 standard. The electrical resistance was monitored simultaneously during the tensile test. Fig.1b shows the configuration of the tensile test.

Results and Conclusions

i. Electrical and tensile properties of GNPs reinforced adhesive

The addition of GNP particles to the adhesive has built up conductive paths and made it electrically conductive. Larger GNPs particles ($25\ \mu m$) mixed with adhesive showed better electrical conductivity than smaller ones ($2\ \mu m$) at the same GNPs loading. Fig. 2 shows the relationship between electrical conductivity vs GNPs loading. The electrical conductivity of epoxy adhesive increased significantly from 10^{-13} to 10^{-3} S/m due to the addition of only 0.75 wt% GNPs. There was no statistically significant difference in tensile strength between pure adhesive (44.8±2.0 MPA) and reinforced with 0.75 wt% of GNPs (43.5±2.0 MPa).

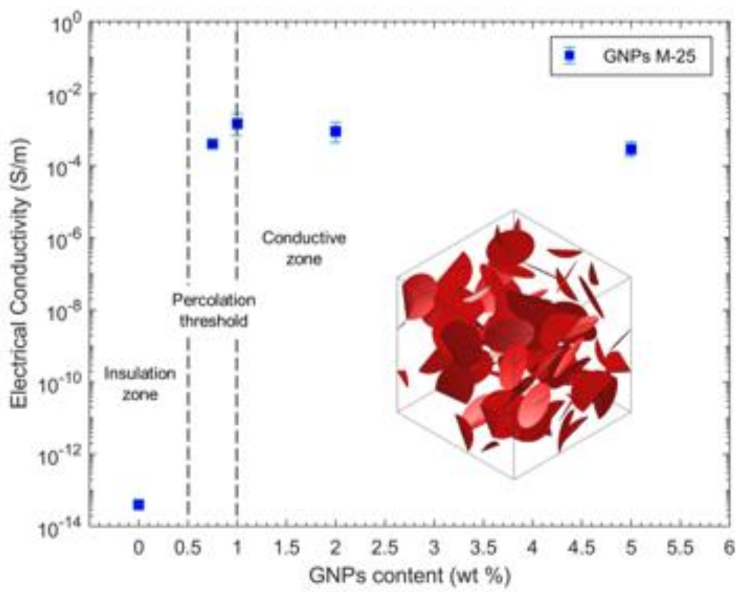

Fig. 2 Relationship of electrical conductivity versus graphene nanoplatelets content

ii. Structural health monitoring

The constructed wireless system successfully monitored the change in electrical resistance of GNPs reinforced adhesive during the lap joint testing. While applying a tensile load to the joint, strain in GNPs reinforced adhesive causes breaking of conductive GNPs paths. This will, in turn, cause the increase in the resistance measurements of adhesive and can be observed in Fig 3. The resistance measurements of GNPs adhesives change proportionally with the tensile load applied. This wireless system in combination with conductive adhesive shows the potential to remotely monitor the structural health of adhesive joints.

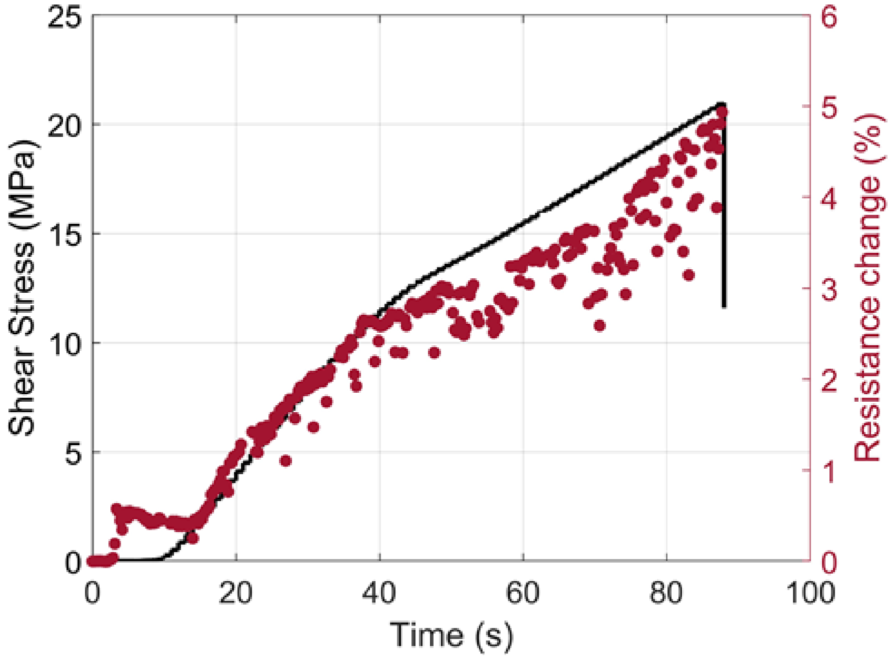

Fig. 3 In-situ monitoring of composite-composite single lap joint.

Deliverables

A peer-review journal paper is in preparation and will be submitted shortly.
The relevant Arduino code and system calibration have been published on GitHub, https://github.com/chieftainmon/ADS1256-calibration