Structural health monitoring via graphene self-sensing adhesive layer joint

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Abstract

This 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 Bluetooth was chosen as the microcontroller and wireless transceiver due to their low energy consumption and modest transmission distance. We have chosen single-lapped FRP composite laminate to demonstrate the system.

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 μm and 25 μm, were tested. The addition of GNPs to the adhesive, above 0.5 wt%, created a conductive path, as shown in Fig.1. 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.

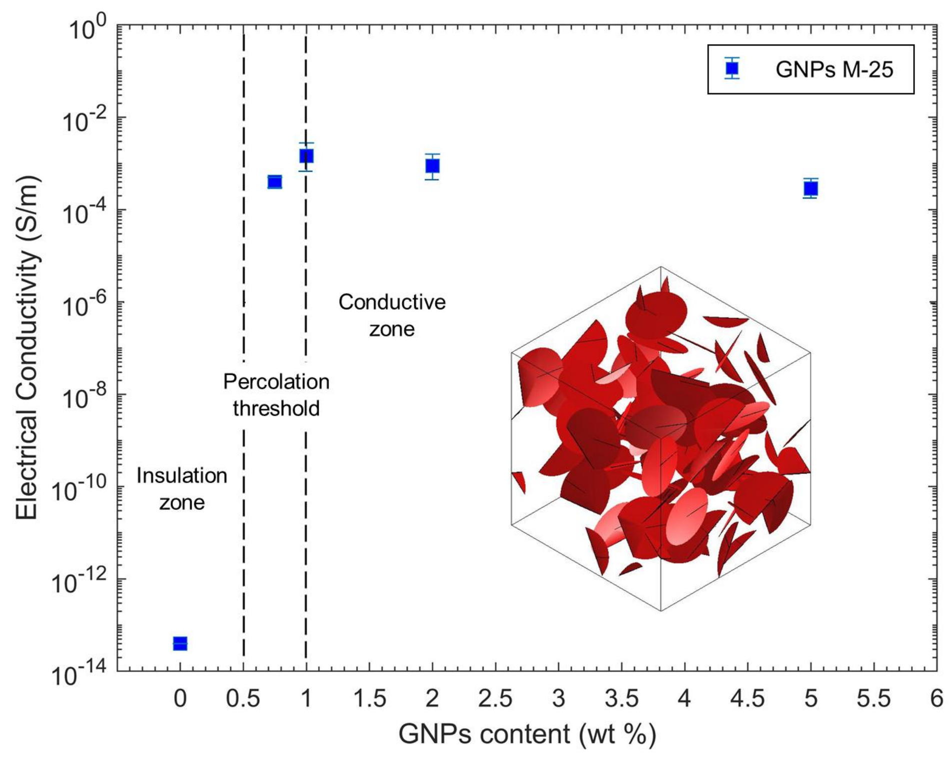

Fig.1 Electrical conductivity versus GNPs loading

Wireless structural health monitoring system

The wireless system is constructed by five core modules:
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.2 shows the wiring of the system.

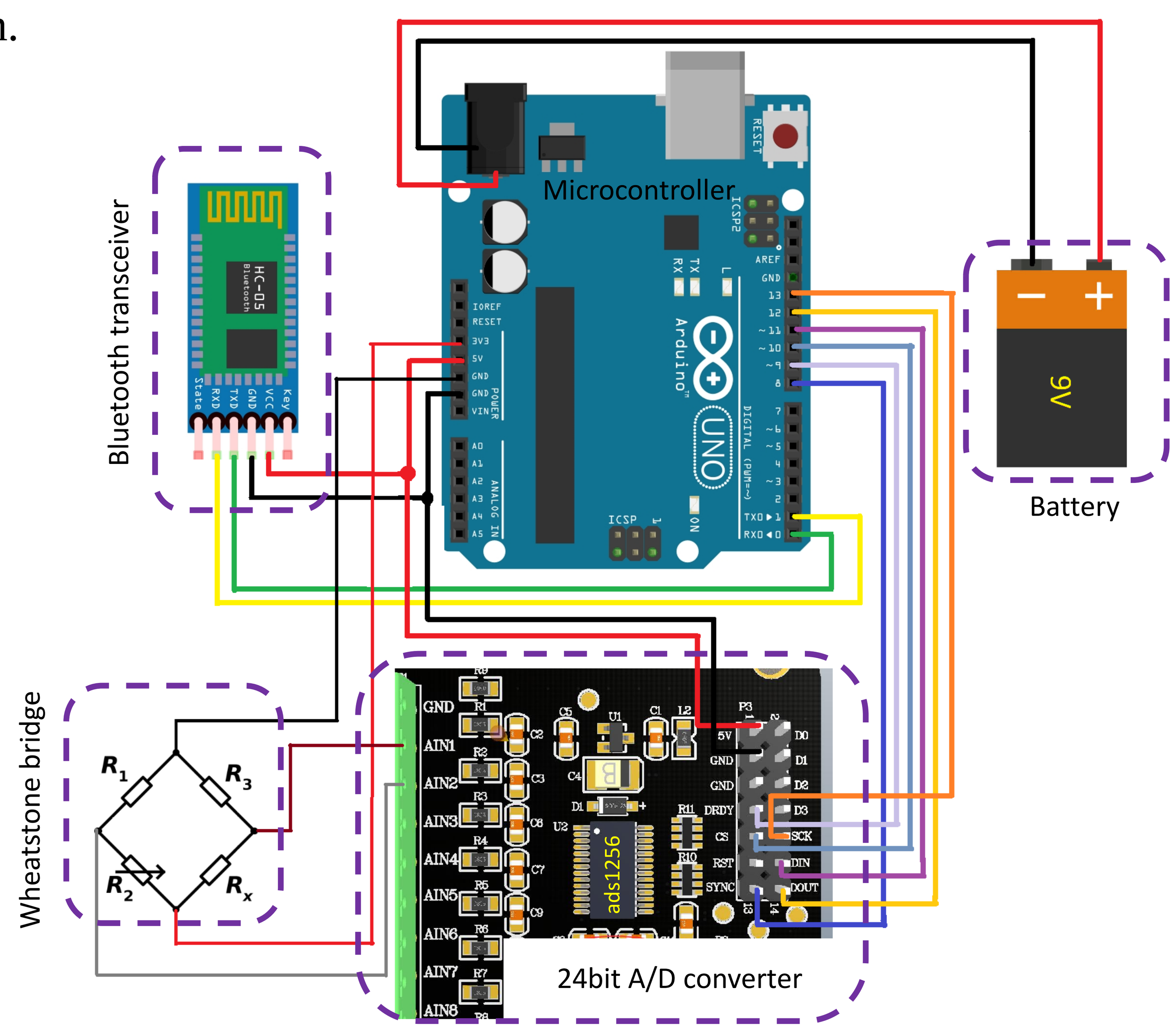

Fig.2 The diagram and wiring of the system

Demonstration

To demonstrate the performance of the system, single-lapped joint FRP composite specimens were prepared, and 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.3 shows the configuration of the tensile test and representative lap shear strength results.

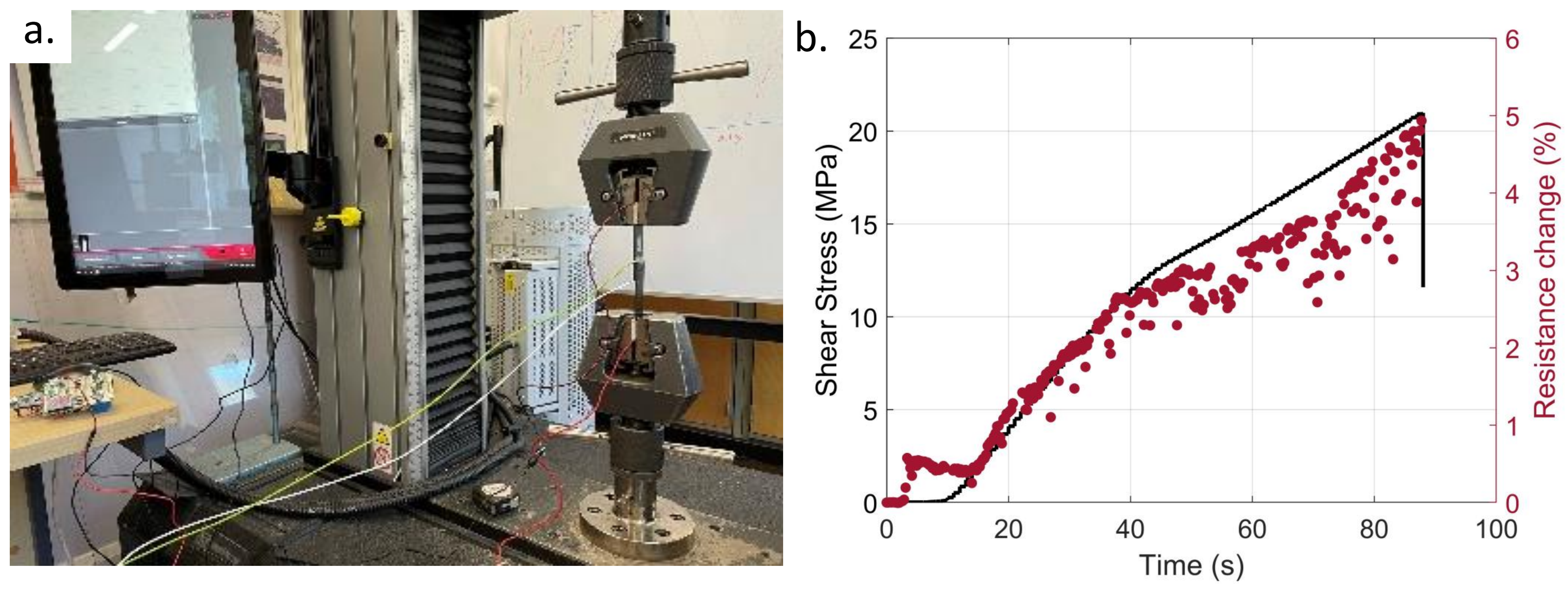

Fig.3 Tensile test setup (a) and representative results of lap shear strength (b)

FEA modelling

The uniform distribution of GNPs has built up bridge network within epoxy resin so that converts it as a conductor. As the carbon fibre is electrically conductive, the GNPs reinforced adhesive and CFRP composite laminate form a close closed circuit. The flow of electric current within the lap-joint specimen was simulated by FEA code (COMSOL Multiphysics). Fig.4 shows the electric current flow within the lap-joint sample. As the transverse conductivity of CFRP composites is considerably lower than that of longitudinal direction, the electric current mainly flows on the surface of the CFRP composite laminate, then enters into the GNPs reinforced adhesive layer.

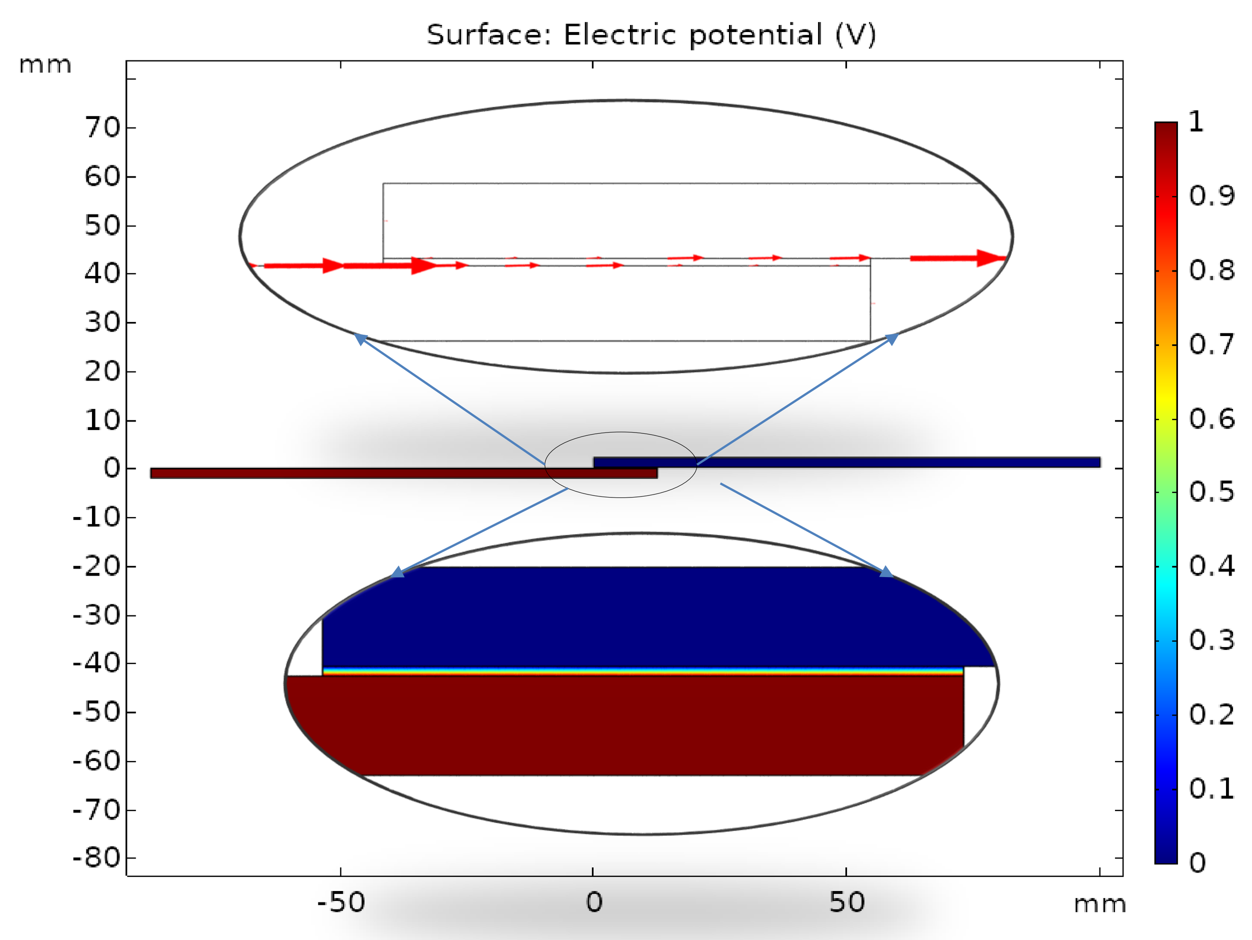

Fig.4 Electrical current flow diagram

Conclusions

- The electrical conductivity of epoxy adhesive increased from 10^{-13} to 10^{-3}S/m due to the addition of 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% GNPs (43.5±2.0 MPa).
- The constructed wireless system successfully monitored the change in electrical resistance of GNPs reinforced adhesive during the applied tensile load.
- This wireless system in combination with conductive adhesive shows the potential to remotely monitor the structural health of adhesive joints.

References

[1] Han et al. 2019, Mechanical and electrical properties of graphene and carbon nanotube reinforced epoxy adhesives: Experimental and numerical analysis, Composites Part A, doi.org/10.1016/j.compositesa.2019.02.027.
[2] Comsol reference manual.

Acknowledgement

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