Institution: University of Chester		
Unit of Assessment: B12 Engineering		
Title of case study: Smart composites with energy harvesting and sensing (Chester Smart Composite Group)		
Period when the underpinning research was undertaken: 2016 – ongoing		
Details of staff conducting the underpinning research from the submitting unit:		
Name(s): Yu Shi Yu Jia	**Role(s) (e.g. job title):** Dr, Research Professor Dr VL Mechanical Engineering	**Period(s) employed by submitting HEI:** 2015 – ongoing 2015 – ongoing
Period when the claimed impact occurred: 2015 – ongoing		
Is this case study continued from a case study submitted in 2014? N		

1. Summary of the impact (indicative maximum 100 words)

Lightweight composite materials have excellent mechanical properties and their use in industrial sectors contributes to zero-carbon emission targets. In our work, smart composites have been developed where energy harvesting and sensors are directly integrated onto the composite substrate using printing techniques. This avoids the use of external sensing devices such as printed circuit boards or batteries, which may be difficult or impossible to apply in harsh environments. They are particularly advantageous wherever sensing or monitoring is necessary in difficult environments where conventional approaches cannot be used. Impact on wind turbine blade structural health monitoring has been demonstrated through field work with the Offshore Renewable Energy Catapult Economic benefits in this application are estimated at £340-£500/kW installed capital cost. Further innovations have been made on the next generation of thermoplastic composites with highly efficient welding, repair, reuse, and recycling developed for extended life cycles.

2. Underpinning research (indicative maximum 500 words)

Multifunctional composites have been developed with novel sensing and energy harvesting capabilities from vibration or solar energies that enable the composite itself to be self-powering. Building our work on failure mechanisms in composites (Yu et al 2014, Yu & Soutis 2015, Liu et al 2017) and energy harvesting (Jia et al 2019, Shi et al 2017), methods have been researched that will benefit a wide application of industries, for example in aircraft wings and offshore wind turbine blades that require structural health monitoring and de-icing *in-situ*. This aspect of the research has been successfully funded by Innovate UK for the "Smart self-sensing wind turbine composite blades for structural health monitoring (SmartBlade)" project with a total budget of £500k. It will reduce maintenance costs and accelerate the application of offshore wind energy. The project consortium is led by Ilika Ltd, with Professor Yu Shi and his Chester Smart Composite Group (CSCG) contributing the design and fabrication of the required smart composites. Field testing was carried out in the Offshore Renewable Energy (ORE) Catapult with input data measured by project partner Titan Wind in China. Titan Wind is the Original Equipment Manufacturer (OEM) of the wind turbine blade with strong interest to exploit this technology. The University of Chester and Nanjing University of Aeronautics and Astronautics (NUAA) have set up a joint research laboratory initiated from this project, and academic outcomes have been published in peer-reviewed Journals (Composite Part B, and Composite Science and Technology) as well as in leading international conferences. Based on the successful dissemination of this research, the CSCG has set up two further international joint laboratories with Xi'dian University and Xi'an Jiaotong University in China.

This project, and subsequent collaborations, has given us the opportunity to undertake further development of our smart composites and its technology, getting us closer to the high technology readiness level (TRL) required to meet industrial challenges in collaboration with local large OEMs including Airbus, Toyota, Rolls-Royce, Bentley and Jaguar-LandRover. We take the main research responsibility to develop multifunctional composite structures using Chester facilities (including the smart composite lab, the laser lab, the design suite, the micro-analysis lab, vibration dynamic lab, and the engineering software for modelling and finite element analysis, etc.).

In related work, the CSCG has been funded through Innovate UK to develop an accurate and lightweight sensing system within wheel kits to *in-situ* monitor the wheel alignment for zero carbon emission for road vehicles, again making use of energy harvesting and vibration analysis expertise (project AutoAlign). The project is led by RL Automotive, with industrial partners Dynamon Ltd and OEM McLaren with Aston University as a further academic partner. We have successfully completed a feasibility study and have subsequently been awarded by £1.5 million for phase 2. Numerical predictions using computational modelling of wheel misalignment effects have been carried out by CSCG, and data and design parameters suggested for hardware selection and integration for experimental monitoring.

The team has also worked on coded materials for windfarm safety, as a subcontracted part of a project led by QinetiQ. The key role of the University of Chester in the project is in developing smart composites by printing functional nanomaterials for wind farm security.

The CSCG is part of a Horizon 2020 project – INTAKE H2020 RISE – a collaborative project with universities from the UK, Poland, Hungary, Japan and China for the development of multifunctional nanocomposites harvesting different types of energies for applications in space, aerospace, automotive, renewable energy and healthcare. The group's involvement is in fundamental aspects of the research where Professor Yu Shi will work on the core technology by designing and printing nanocomposites for energy harvesting purposes.

3. References to the research (indicative maximum of six references)

Journal publications:

- *Narita F, Wang Z, Kurita H, Li Z, Shi Y, Jia Y, Soutis C*. A review of piezoelectric and magnetostrictive biosensor materials for detection of Covid-19 and other viruses. *Advanced Materials 2020, 2005448*
- *Jia Y, Wei X, Xu L, Wang C, Lian P, Xue S, Al-Saadi A,* ***Shi Y***. Multiphysics vibration FE model of piezoelectric macro fibre composite on carbon fibre composite structures. *Composite Part B 2019; 161: 376-85.*
- Liu Q, Xu X, Ma J, **Shi Y,** Hui D. Lateral crushing and bending response of CFRP square tube filled with aluminium honeycomb. Composite part B 2017; 118: 104-15.
- ***Shi Y****, Hallett S, Zhu M.* Energy harvesting behaviour for aircraft composites structures using macro-fibre composite: Part I-Integration and experiment. *Composite Structures 2017; 160: 1279-86..*
- ***Shi Y****, Soutis C.* Modelling transverse matrix cracking and splitting of cross-ply composite laminates under four point bending. *Theoretical and Applied Fracture Mechanics 2015; 83: 73-81.*
- ***Shi Y****, Pinna C, Soutis C.* Modelling impact damage in composite laminates: A simulation of intra- and inter-laminar cracking. *Composite Structures 2014; 114:10-9.*

4. Details of the impact (indicative maximum 750 words)

The successful outcomes of "SmartBlade" have demonstrated a new generation of integrated smart composites. The smart composite is able to perform self-structural health monitoring through vibration spectrum analysis, and anti- and de-icing, self-powered by harvesting offshore environmental vibration energy. Key elements of innovation include flexibility in solid state battery and electronics design; development of a composite piezoelectric transducer for sensing, actuation and generation; as well as advanced manufacturing and integration of the functional layers onto the curved composite stack.

A case study demonstration has been performed in ORE Catapult in Blyth for field testing of conditional monitoring of wind turbine blades by project lead Ilika. Real wind farm data has been measured at the wind farm of project partner, Titan Wind. The measured vibration data embedded into the wind turbine blade during service was used for testing the energy harvesting for structural health monitoring. The field testing has demonstrated the developed energy harvesting from offshore environmental vibration could keep charging the micro-battery developed by Ilika and so in turn power monitoring sensors and wireless communication (https://www.ilika.com/latest-news/successful-stereax-field-trial).

The collaboration of SmartBlade, helped project lead Ilika for the first time to explore the application of their solid-state batteries to offshore renewable energy. The project has successfully helped them to set up the partnership with Chinese industries Titan Wind and Envision, who have been OEMs with global reputations in renewable energy (https://www.ilika.com/latest-news/new-partnership-with-wind-turbine-manufacturer-in-china). It also offers a step-change reduction in the operating costs of wind turbines, with IoT (Internet of Things) solutions for the reduction of high maintenance costs and other difficulties in offshore wind turbines.

It has been estimated to reduce the operation and maintenance (O&M) costs with circa 10% off and increased safety of operation of offshore wind energy, the research contributes towards the continued economic expansion of the primary application sectors. Furthermore, there is a significant contribution towards reduction of pollution and carbon emissions (20% decrease in 2017, and expected 24% reduction by 2030 and 80% by 2050), because the smart composite would expand the use of renewable energy by citizens in both the UK and China due to the reduced O&M costs. Overall, in addition to the economic benefits (estimated reduction of £340-500/kW of capital costs), the research has impact on conservation of the environment, improvement in public health, and reduction of pollution and carbon emissions, thereby helping slow the effects of climate change.

The first stage of “AutoAlign” has been funded by Innovate UK with automotive SME lead, RL Automotive with UoC where the prototype of concept has been proved to develop a built-in electronics system to monitor the wheel conditions for reduction of carbon emissions from tyres *in-situ*. Due to the first stage’s success, the Innovate UK has funded £1.5 million to the consortium to develop this technology towards commercialisation. The success of the first stage attracted OEMs and end users McLaren, Scania, and Tesco to join the consortium, who expected to improve fuel efficiency, extend wheel/tyre life, and reduce carbon emissions by the efficient wheel monitoring of their road vehicles, especially for heavy vehicles such as trucks. The project is estimated to contribute extension of tyre life (one degree’s wheel misalignment reduces 7% of tyre life) in truck wheels, saving 30% of vehicles those might suffer from misalignment of wheels. The eventual goal is to reduce the 4-13% of all PM 2.5 emissions from tyre and road surface wear (see statement from RL Automotive).

5. Sources to corroborate the impact (indicative maximum of 10 references)

External fund:

- SmartBlade: This is a joint project funded (total £500k) by Innovate UK for SME lead, Ilika, and University of Chester to develop smart composite for offshore wind turbine blades with reduced maintenance costs so that further accelerating the application of offshore wind energy. The purpose is to reduce the operation and maintenance (O&M) costs to accelerate the wind energy use in the UK, which could be found by reports by links below:
- https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/650586/Jiangsu-UK_Industrial_Challenge_Programme_-_Infra_-_Competition_Results.pdf
- https://www.ilika.com/latest-news/new-partnership-with-wind-turbine-manufacturer-in-china
- https://www.ilika.com/latest-news/successful-stereax-field-trial

The academic partnership between University of Chester and NUAA set up the joint research lab initiated from this project. The academic outcomes have been published in peer-reviewed Journals (see references below) as well as international conferences, DAMAS, ICCM, Powermems 2019 etc.

- *Pan L, Zhang A, Zheng Z, Duan L, Zhang L, **Shi Y**, Tao J.* Enhancing interfacial strength between AA5083 and cryogenic adhesive via anodic oxidation and silanization. *International Journal of Adhesion and Adhesives 2018; 84: 317-24.*

- *Wen T, Ratner A, Jia Y, **Shi Y**.* Parametric Study of Environmental Conditions on The Energy Harvesting Efficiency for The Multifunctional Composite Structures. *Composite Structures 2020, 112979*

- *Pan L, Pang X, Wang F, Huang H, **Shi Y**, Tao J.* Effect of surface micro-pits on mode-II fracture toughness of Ti-6Al-4V/PEEK interface. *Composite Structure 2019; 229(1): 111333.*

- *Alsaadi A, **Shi Y**, Jia Y.* Delamination detection via reconstructed frequency response function of composite structures. *Processdings of the 13th International conference on damage assessment of structures 2019; 837-43.*

- *Alsaadi A, Tao J, Pan L, Jia Y, **Shi Y**.* Vibration energy harvesting of multifunctional carbon fibre composite laminate structures. *Composite Science and Technology 2019; 178: 1-10.*

- *Jia Y, Wei X, Xu L, Wang C, Lian P, Xue S, Al-Saadi A, **Shi Y**.* Multiphysics vibration FE model of piezoelectric macro fibre composite on carbon fibre composite structures. *Composite Part B 2019; 161: 376-85.*

- ***Shi Y,** Jia Y.* Multimodal shear wave deicing using fibre piezoelectric actuator on composite for aircraft wings. *IEEE/ASME Transactions on mechatronics 2018. 23(5): 2090-98.*

- AutoAlign: This is an Innovate UK funded project and led by SME RL Automotive, with industrial partners Dynamon and OEM McLaren as well as academic partner University of Chester and Aston University. The purpose is to develop an accurate and lightweight sensing system to in-situ monitor the wheel alignment for zero carbon emission for road vehicles. We have successfully completed the phase 1 study as feasibility and then been awarded by £1.5Million for phase 2 currently. Benefit to this project, a new PhD investment has been done by collaborative company RL automotive with university of Chester. The relative publication has been produced by

- *Jia Y, Li S, **Shi Y.*** An analytical and numerical study of magnetic spring suspension with energy recovery capabilities. *Energies 2018; 11: 3126.*

- Coded material for windfarm safety: This is a subcontracted project by lead industry QinetiQ. University of Chester plays the key role with QinetiQ for developing the smart composite by printing functional nanomaterials for wind farm security, with £63k received.

- INTAKE H2002 RISE (total €792k): This is a collaborative project with universities from UK, Poland, Hungary, Japan and China (Aston University; Politechnika Wroclawska (Poland); Energyatudomanyi Kutatokozpont (Hungary);Tohoku University (Japan); Waseda University (Japan); Tsinghua University (China); The University of Nottingham Ningbo (China)) for multifunctional nanocomposite to harvest different types of energies for applications of space, aerospace, automotive, renewable energy and healthcare. It is fundamental research where Professor Yu Shi at University of Chester will work on the core technology by design and printing nanocomposite for energy harvesting purpose. The collaborative co-authored publication has been published:

- *Narita F, Wang Z, Kurita H, Li Z, Shi Y, Jia Y, Soutis C.* A review of piezoelectric and magnetostrictive biosensor materials for detection of Covid-19 and other viruses. *Advanced Materials (**Impact factor: 27.398**) 2020, 2005448*