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En route to “Massless Energy” With Structural Power Composites

Structural power composites are structural composites with the additional functionality of storing electrical energy. Central to this research is SORCERER, an EU Clean Sky 2 project, in which Imperial College London, Chalmers, KTH and IMDEA, under the technical guidance of Airbus, are demonstrating structural power in aerospace components. The concept is based on the fact that carbon fibers can offer several functions: high stiffness and simultaneously being used as active electrodes. Combined with a multifunctional matrix allowing not only for load transfer but also for ion-conductivity, multifunctional carbon fibre composite laminates can be made with either an integrated supercapacitor or battery function. Compared to two monofunctional systems, a structure and a separate energy storage device, multifunctional structural power composites will have a lower mass while providing the same structural and energy storage functions, offering a new approach to enhancing sustainability in several Sectors.

Here we provide a brief insight into this emerging field, and present an industrial perspective on the potential impact of structural power composites.

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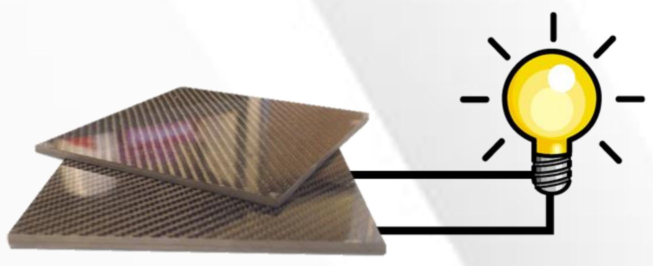
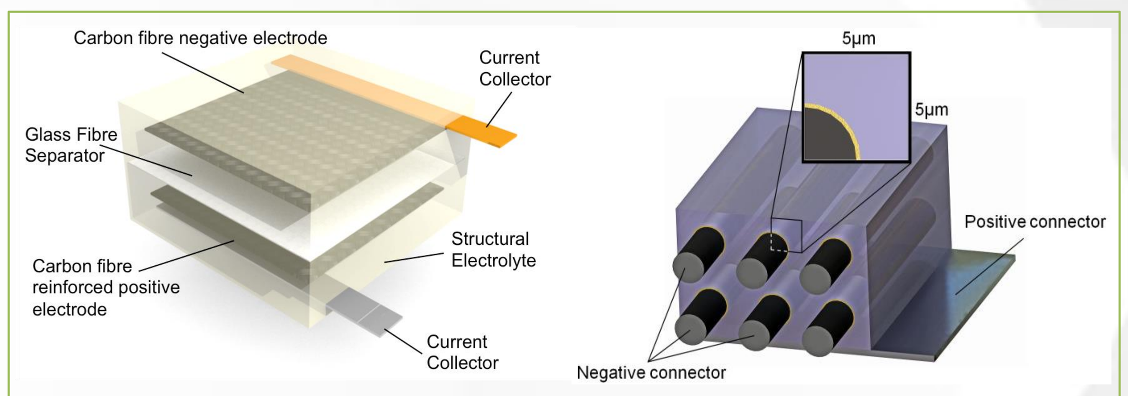


Introduction

Lightweighting and energy storage are critical to transportation: composites have been at the forefront of the former for decades, their adoption providing significant reductions in system mass and hence emissions. However, a completely new solution to both lightweighting and energy storage is emerging: structural power composites. These are structural composites with the additional functionality of storing/delivering electrical energy. This should not be confused with multifunctional structures where conventional energy storage devices (e.g. batteries) are sandwiched within conventional composite laminates: in structural power composites the constituents (fibres and matrices) synergistically and simultaneously undertake both structural and electrochemical roles. Polymeric composites provide compelling opportunities here: the laminated architecture and the use of carbon are common to both structural composites and energy storage devices. Melding of functions is a step change in how we use polymeric composites, going beyond the conventional monofunctional structural roles. This emerging field is presenting considerable technical challenges, but promise exciting opportunities in transportation and portable electronics.



(Left) Concept of a laminated structural carbon fibre battery and (Right) the concept of a 3D structural carbon fibre micro battery architecture.

Structural Batteries

A structural battery is a material that carries mechanical load while simultaneously providing electrical energy storage as a battery. A novel Li-ion battery material is being developed employing carbon fibres as combined electrode and reinforcement, and structural battery electrolytes as the matrix for simultaneous Li-ion transport and mechanical load transfer. These materials are anticipated to significantly reduce vehicle system weight and allow electrical energy storage in the structural load path of electrical vehicles. Two architectures have been conceived for making such structural batteries as depicted above: the laminated battery and 3D micro battery.

A laminated structural battery resembles a conventional fibre composite laminate (above - left). Carbon fibres are used as reinforcement and laid up in arbitrary angles in the sequence: negative electrode/separator/positive electrode. The carbon fibres in the negative electrode intercalate ions (herein Li-ions) the same way as a state-of-the-art Li-ion battery electrode made from graphite. The separator could be a thin glass fibre weave or veil. The carbon fibres in the positive electrode are coated with an active battery material, e.g. LiFePO4. These layers are then embedded in structural battery electrolyte to achieve mechanical load transfer and ionic conductivity.

Laminated structural battery composites rely on access to a highly ion conductive, and stiff, solid polymer electrolyte (SPE). To mitigate the low conductivity of most SPEs a 3D structural battery composite architecture has been proposed, in which each individual carbon fibre is coated by a thin SPE in an electro-polymerisation process resulting in a distance between the electrodes less than 500 microns. The SPE coating also electrically insulates the carbon fibres from the positive electrode, which is distributed in the matrix surrounding the coated fibres, as illustrated above-right. The 3D battery design has considerable attractions, but efficient fabrication methods are lacking. In contrast, the laminated composite battery can be made in large volumes. With the technologies developed in SORCERER we expect to demonstrate a 28 V structural battery device with an energy density of 100 Wh/kg.

Structural Supercapacitors

For applications in which energy delivery (i.e. power) and cyclability, rather than energy capacity, is required, an alternative to batteries are supercapacitors. These devices store energy through accumulation of ions at the electrodes. Structural supercapacitors (see below) have two high surface area electrodes sandwiching a separator, all infused with a structural electrolyte.

Imperial College London have developed Textreme spread-tow woven carbon fibre lamina which are infused with a carbon aerogel, with polymeric non-woven separators. The structural electrolyte is a blend of ionic liquid and epoxy, the microstructure of which can be tailored. The current devices have energy and power densities of 1.4 Wh/kg and 1.1 kW/kg, respectively (N.B. COTS supercapacitors are 4.7 Wh/kg and 4.1 kW/kg, respectively). In parallel with the device development, Imperial College London are formulating design methodologies for structural power and developing combined numerical models for both electrochemical and mechanical prediction. This will permit modelling of any coupling behaviour between functions as well as a tool for parametric studies and support certification.

A promising strategy for structural supercapacitors is combining traditional reinforcing fibres with nanostructured fibres. With electrical conductivity superior to that of carbon fibre (≈10^5 S/m) and roughly 1000x more specific surface area, unidirectional non-woven fabrics of carbon nanotube fibres (CNT) can simultaneously perform electric double layer capacitive storage and current collector functions (see below). Structural supercapacitors can be produced by integrating pre-patterned CNT fibre fabrics, a polymer electrolyte and a conventional fibre fabric, followed resin infusion. By monitoring the electrochemical properties during mechanical testing, we observe complete tolerance against large deflections, with capacitance remaining stable after fatigue tests compared with a 50% reduction in performance for reference embedded devices (i.e. a multifunctional structure).

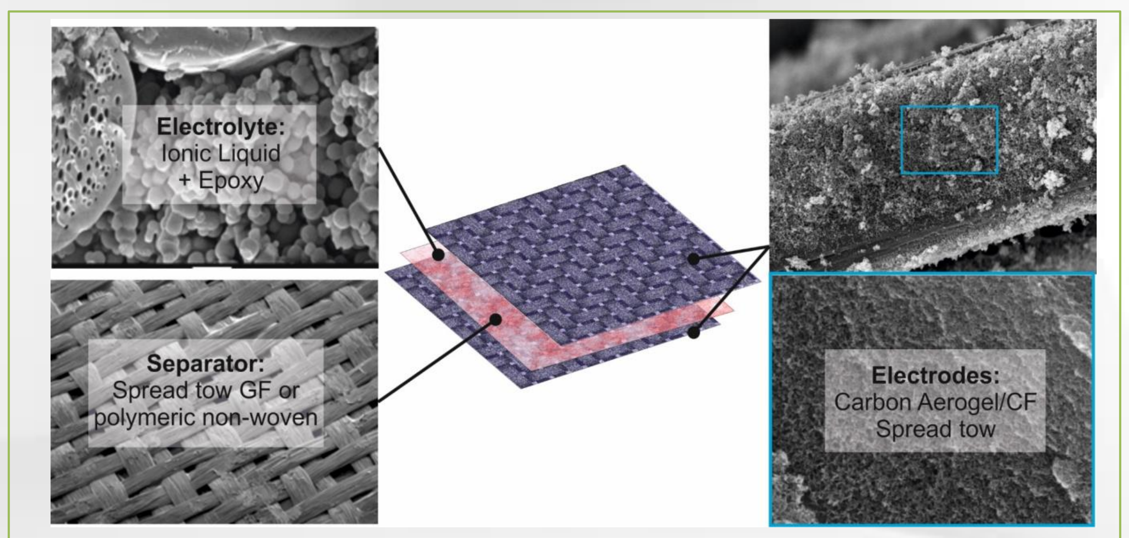
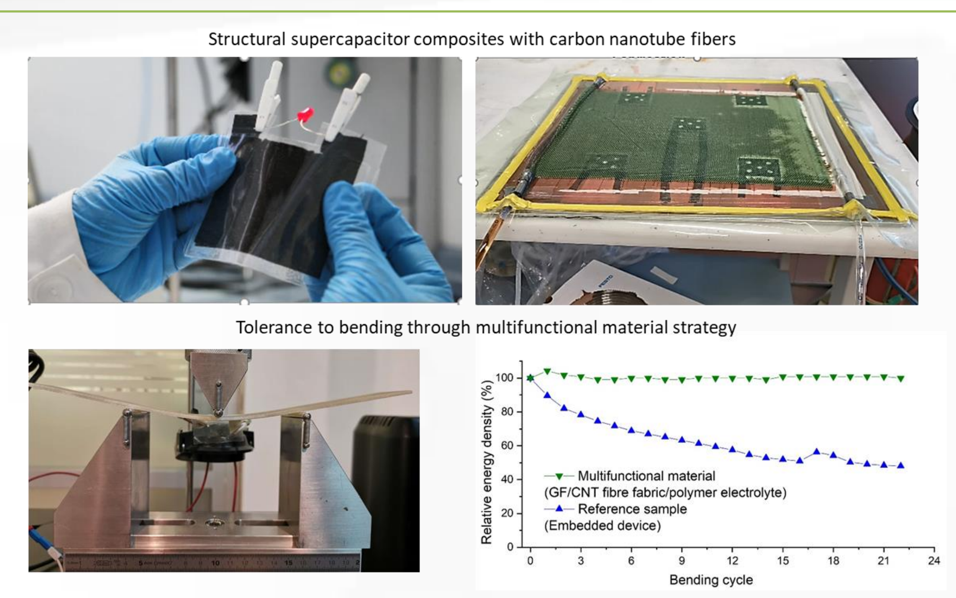


Illustration of a structural supercapacitor.



Structural energy storing composites based on macroscopic reinforcing fibres, high-capacitance fabrics of CNT fibres and polymer electrolytes.

Industrial Outlook

Throughout the development of structural power materials, the SORCERER team have cooperated with industry to produce demonstrators to pull through this technology. For example, the STORAGE project developed a multifunctional bootlid for a Volvo S80, which contained four stacks of four structural composite supercapacitors (see below). As well as providing electrical power, this led to a weight reduction from 13 kg (conventional component) to 5.2 kg. In SORCERER, the team are developing several demonstrators, including a multifunctional C-section fuselage beam which will replace an existing supercapacitor bank in the aircraft cabin (below).

However, considerable hurdles still must be overcome for structural power to be fully adopted by industry. Fundamental challenges include improved understanding of the interaction between electrical and mechanical behaviour, performance at temperature extremes and durability. Practical issues, such as accessibility, replaceability, sensing and battery management will also have to be addressed. A particular challenge associated with Aerospace is addressing certification of structural power materials such that they are deemed airworthy.

(Top) Volvo S80 composite bootlid with four stacks of four structural supercapacitors within; (Bottom) fuselage C-beam multifunctional demonstrator replacing supercapacitor bank

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Sponsors

Industrial support

The current developments of structural power composites represent the first steps in an exciting vision in which equipment, transportation and infrastructure will contain their own energy supply as their mechanically load-bearing structure! Structural power composites will lead to mass savings, and thus energy savings, enabling electrification in a number of applications such as aircraft and road vehicles, and portable electronics.

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