

## **Structural batteries**

#### Multifunctional composites for energy storage and ...



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## Importance of weight in aerospace







# Flying all-electric?

### A319: 800 nm / 140 PAX

Energy Density of Kerosene12000 Wh/kgEnergy Density of Battery120 Wh/kg

- $\rightarrow$  Conventional, 30 kg Kerosene/PAX
- → Fully Electric, 1000 kg Battery/PAX





## Importance of weight for land transport







## Need for electrification of future vehicles

Structural batteries a possible enabler?

Mechanical structure, m<sub>s</sub> Rechargeable battery pack, m<sub>b</sub>

Structural battery,  $m_{sb}$  $m_{sb} < m_s + m_b$ 



1500 kg Structure+systems



600 kg Batteries





## The Li-ion battery





## **Device Architectures – Structural Battery**



### Laminated architecture

 Requires highly conductive electrolytes

### Fibre architecture

 Does not require highly conductive electrolytes



## **Capacity of carbon fibers**





## **Structural Battery Electrolyte**



Bisphenol A dimethacrylate

Bisphenol A dimethacrylate and Bisphenol A ethoxylate dimethacrylate Bisphenol A ethoxylate dimethacrylate

Storage modulus 680 MPa Conductivity 1.5×10<sup>-4</sup> S/cm

Ihrner et al, J.Mat.Chem.A., 5, 2017



# Structural negative half cell – multifunctional performance

#### Electrochemical

Cycling efficiently Capacity ≈ 230 mAh/g



#### Mechanical (lamina data) $E_1 \approx 52 \text{ GPa} (\text{now} > 100 \text{ GPa})$ $E_2 \approx 1.7 \text{ GPa}$ $G_{12} \approx 1.5 \text{ GPa}$ $\sigma_1 \approx 1000 \text{ MPa}$ $\sigma_2 \approx 12 \text{ MPa}$ $\tau_{12} \approx 13 \text{ MPa}$ Vacuum Infusion of SBE into Carbon Fibers Dry and Spread Carbon Fibers



Johannisson et al, Compos Sci Technol, 162, 2018



## **Structural negative half cell - Interface**

Uncycled sample

Electrochemically cycled sample



Phase-separation is bicontinuous at the carbon fiber interphase

Johannisson et al, Compos Sci Technol, 162, 2018



**Positive electrode** 

#### **One possible route**

Coat active materials onto carbon fibres? Electrophoretic deposition of LiFePO<sub>4</sub>



Hagberg et al, Compos. Sci. Technol., 162, 2018



## **On-going - Full Cell**





# Structural battery modelling – multifunctional performance



#### **Designing a structural battery**

- Comparing to a conventional carbon fiber composite plate
- Comparing to a standard lithium ion battery



## Car roof







Original roof Steel Mass 18.7 kg Lithium ion battery 6.3 kg Updated roof Epoxy and carbon fibers Mass 5.7 kg Lithium ion battery 6.3 kg 51% mass saving versus original design

Multifunctional roof Structural battery Mass 9.6 kg Corresponding lithium ion battery 6.3 kg 62% mass saving versus original design 20% mass saving versus updated design



## **Electric ferry**



Electric ferry



#### Original face sheets Epoxy and carbon fibers Mass 2.4 kg

Lithium ion battery 3.8 kg



#### Multifunctional face sheets Structural battery Mass 5.5 kg 11% mass saving



## Laptop computer chassis





Original chassis Steel Mass 0.15 kg Lithium ion battery 0.09 kg



Updated chassis Epoxy and carbon fibers Mass 0.1 kg Lithium ion battery 0.09 kg 21% mass saving versus original design VS.



Multifunctional chassis Structural battery Mass 0.15 kg 38% mass saving versus original design 19% mass saving versus updated design



## **Carbon fibre lithiation expansion**



Johnson, D. J., *J. Phys. D Appl. phyics* **20**, 286–291 (1987)





# Shape-morphing composite





## **Actuation demonstrator**

https://play.kth.se/media/Movie+S1/0\_5ntruhqj



## Vision

"A composite material that carries load, stores electrical energy, senses its own state, morphs and harvests energy"





#### You cannot do this alone! Polymers: Fibers: Mats Dan Johansson Zenkert **Structural** Battery Materialmaterials Mechanical modelling: properties: Janis Leif Asp Varna Electrochemistry:

Göran Lindbergh



CHALMERS









# Questions?



The Economist





New York Times

Plastic composite supercapacitor

Insulating fibreglass layer







Materials world



**CNBC** www.energyopportunities.tv/Editorial-Features/Anenergy-storage-revolution