Next Generation of 3D Printed Structural Supercapacitors (PRINTCAP)

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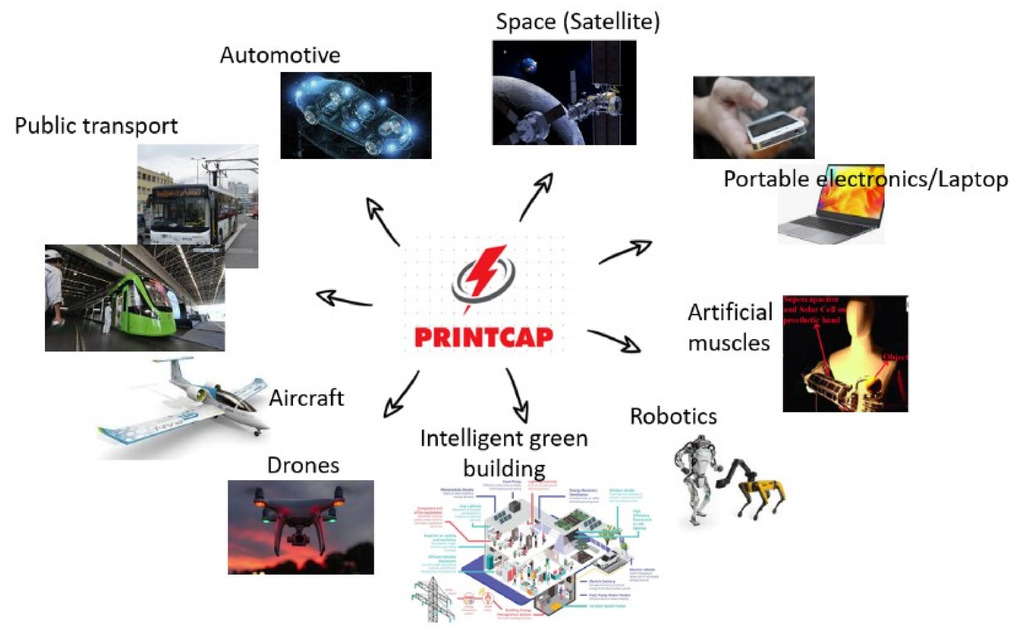
Motivation

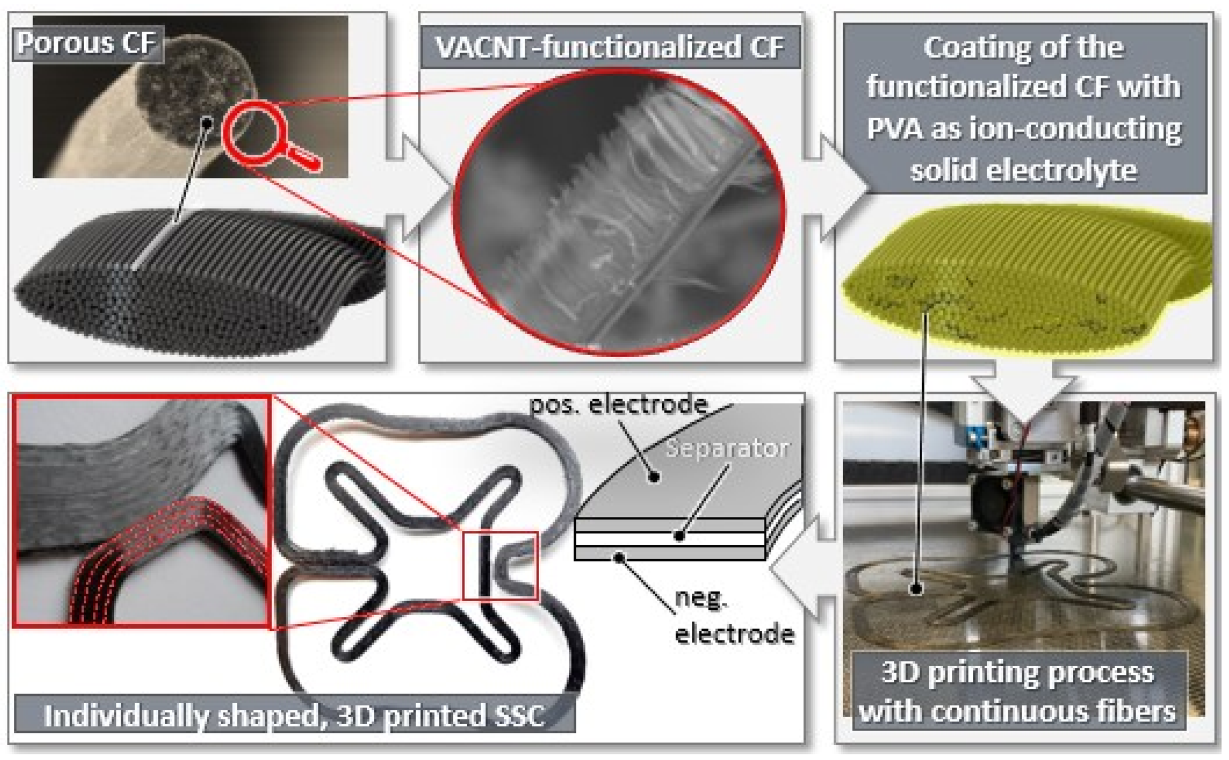
- **Lightweight energy storage** is essential for electromobility and aerospace applications.
- **Conventional batteries** are heavy and limit design flexibility.
- **Structural Supercapacitors (SSCs)** combine mechanical strength with energy storage, reducing weight by **up to 27%.**
- **High energy rates** make SSCs ideal for **highly dynamic systems**.

➔The **PRINTCAP project** develops **SSC solutions** using **additive manufacturing (AM)** and **multifunctional composites** for next-generation applications.



Objectives

- **Material Development:**
  - **Carbon fibers functionalized with vertically aligned carbon nanotubes (VACNT)** for high surface area.
  - **Solid-state high-ionic-conductivity electrolytes** for mechanical robustness.
- **Manufacturing Approach:**
  - **Endless-fiber 3D printing** to create SSCs with tailored geometries.
  - **Use of multiscale multiphysics modeling** to optimize and capture the interaction between mechanical deformation, filament arrangement and energy storage behavior.

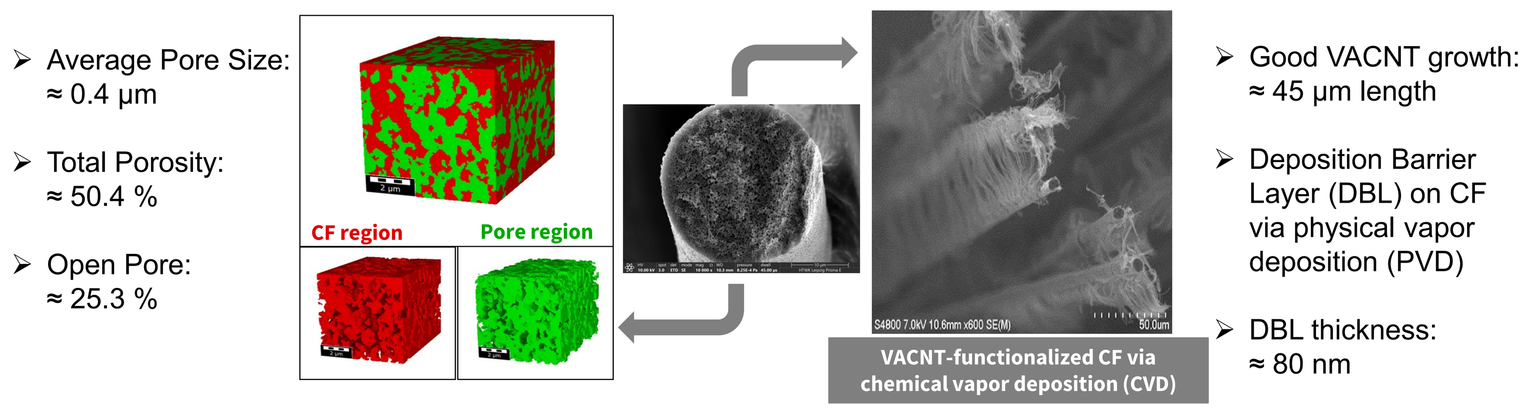


Characterization routine

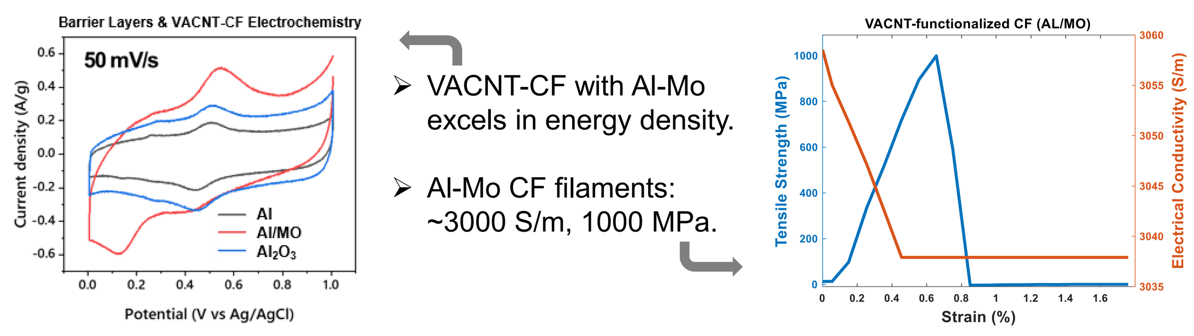
1. **Porosity and Structural Characterization**
   - X-ray microscopy to analyze pore structure.
   - SEM imaging to assess VACNT-modified carbon fibers.
2. **Electrochemical Testing**
   - Fiber electrochemical tests to measure current density.
   - Cyclic voltammetry analyses of PVA gel electrolyte
3. **Mechanical Testing**
   - Tensile tests to evaluate fiber strength.
   - PET-G-CF layer characterization for encapsulation and reinforcement.
4. **Multiscale Multiphysics Modeling for SSC**
   - Simulates mechanical-electrostatic coupling.
   - Develops a predictive model for SSC behavior.
   - Optimizing design parameters and filament arrangement for SSC capacitance.
5. **Modeling and Simulation**
   - Finite Element Analysis (FEA) to determine reinforcement layer thickness for drone applications as a proof of concept.

Results & Discussion

- **Material development:** Micro-scale pore network in porous CF visualized using SEM and 3D X-ray microscopy.



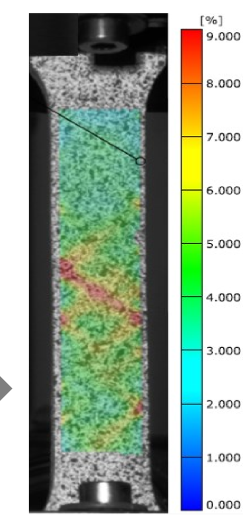
- **CF:** Electrochemical, Electrical & Mechanical Tests



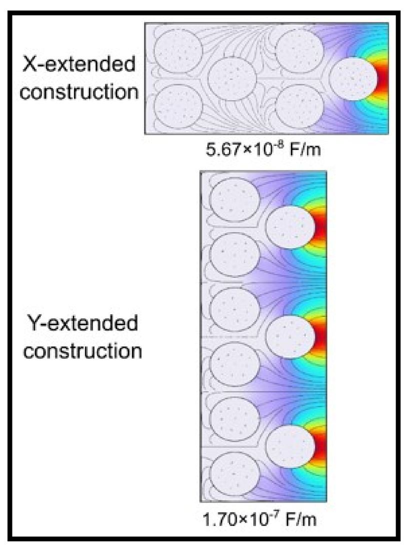
- **Reinforcement layer:** Mechanical and DIC results

➢Tensile strength: 58 MPa, Elongation at break: 4.5.

➢DIC camera results: 9% elongation at the center of the tensile sample



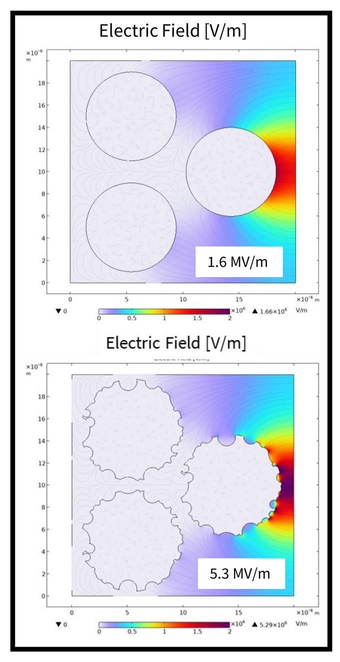
- **Modeling framework for SSC**



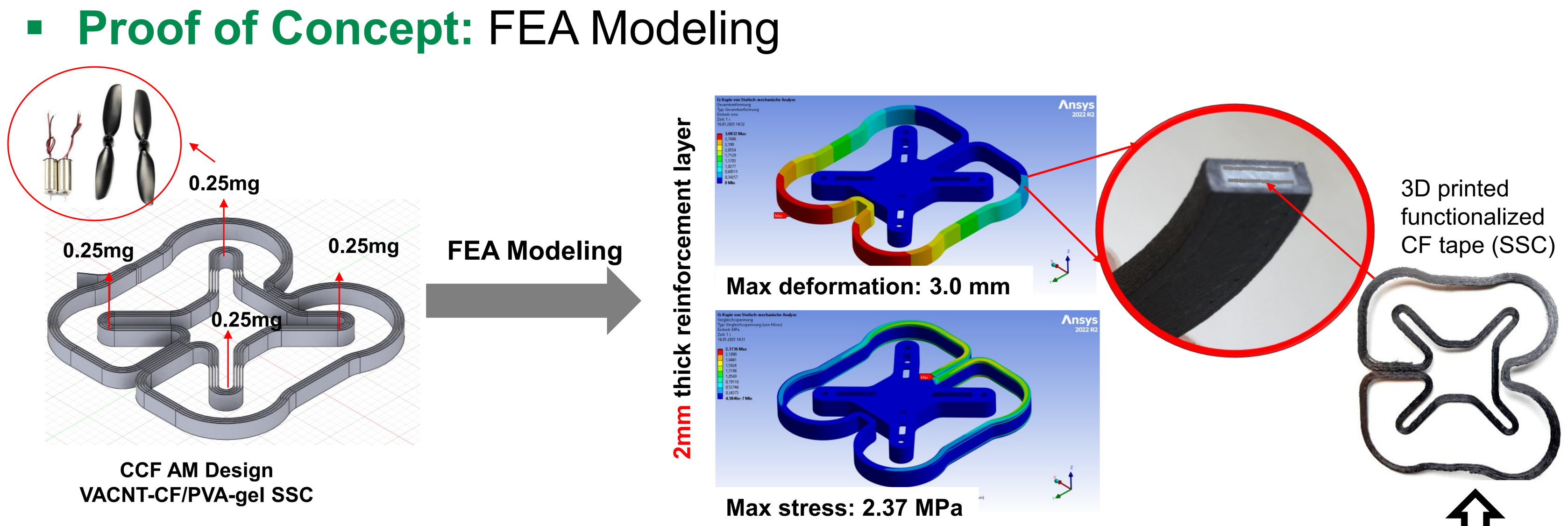
➢Y-extended construction achieves higher capacitance (F/m).

➢The screening effect must be considered in design.

➢Surface porosity enhances charge storage.



- **Proof of Concept:** FEA Modeling



- **Drone Performance:** 15s hover at 30 cm requires 45 W power and 0.20 Wh energy.
  → 30.14 g SSC must deliver 1.49 kW/kg and 6.63 Wh/kg.

Conclusion

➢ Closed and isolated pores do not affect charge storage, while surface porosity (high surface area medium) enhances it—explaining why VACNTs significantly boost capacitance.

➢ A thin, densely packed CF is the optimal design for SSCs.

➢ PRINTCAP successfully demonstrates TRL 1→3 advancement in SSC technology.

➢ 30.14 g of VACNT CF/PVA gel SSC delivers the energy for a 15-second hover at 30 cm.

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