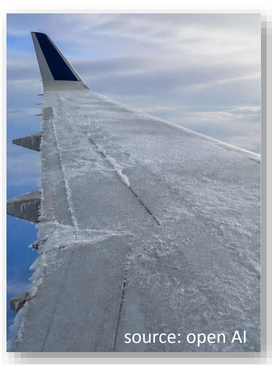
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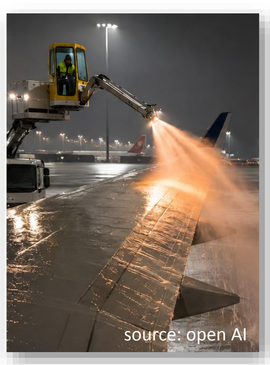
DEVELOPMENT OF CONDUCTIVE COATINGS FOR SUSTAINABLE ANTI-ICING SYSTEMS

Introduction

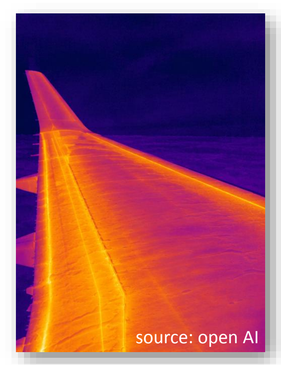
Ice accretion
Economic and safety issues in:
- wind power
- aviation
- railway industry



Current solution
chemical de-icing
- expensive
- time-consuming
- high chemical consumption
- harmful to the environment and people

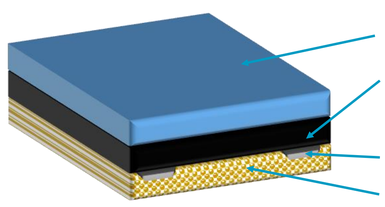


Aim
Development of active anti-icing system based on modified conductive coatings made of carbon-based nanoparticles and unsaturated polyester resin that can be utilized in flexible manufacturing processes of fibre-reinforced composites.



Approach

Development of a flexible, heatable gelcoat layer based on unsaturated polyester for integration into fibre-reinforced composite components



Unsaturated polyester (UP) resins are used in the manufacture of moulded parts and glass-fibre-reinforced composite materials (e.g. aeroplane wings). Curing takes place via a radical cross-linking reaction. Application by spread coating is not yet widely used and places certain demands on the UP:
- cross-linking temperatures > 60 °C
- pot life of a few hours
- no strong exothermic reaction
- styrene-free
- ability to produce flexible coatings

→ Styrene-free, water-emulsifiable unsaturated polyester resin fulfills the requirements.

Carbon nanotubes (CNTs) are a promising approach to increase a material's conductivity and thus enable heatability. However, their tendency to agglomerate presents challenges in dispersing them in polymer matrices. In order to avoid shortening of the CNTs, **three-roll milling** enables a more uniform dispersion in highly viscous polymers. To date, only a few studies have investigated the dispersion of CNTs in thermoset matrices, with varying success in achieving high conductivity at low CNT loadings.



Processing on three-roll mill

Processing procedure for flexible, heatable coatings of unsaturated polyester resin

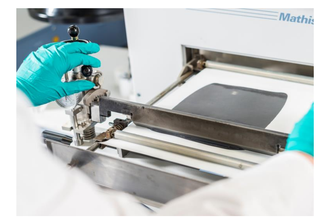
Unsaturated polyester
(styrene-free, water-emulsifiable)
+ water + CNTs
+ dispersing additives
+ accelerator: Co^{2+} + initiator: peroxide

↓

Processing the paste
- homogenisation in speed mixer
- processing on three-roll mill

↓

Production of flexible layers
- on labcoater with release paper
- optimized heating conditions: 5'/110 °C, 5'/160 °C



Application of the dispersion on labcoater



Flexible composite material

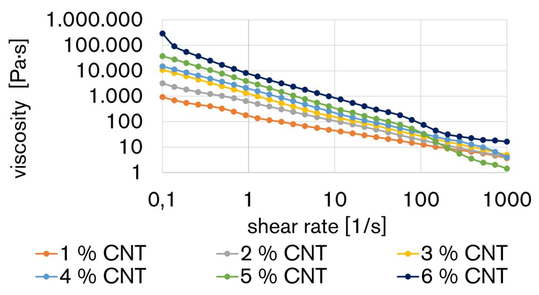
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Application of conductive lines: Cu or waterborne PU paste with Ag

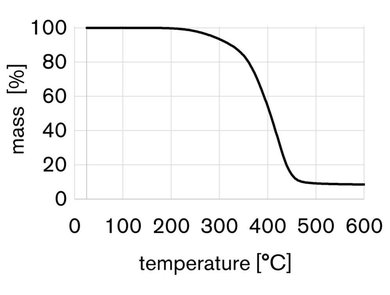
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Production of flexible composite material
- Application of another UP-layer with CNTs
- Lamination of glass fibre nonwoven

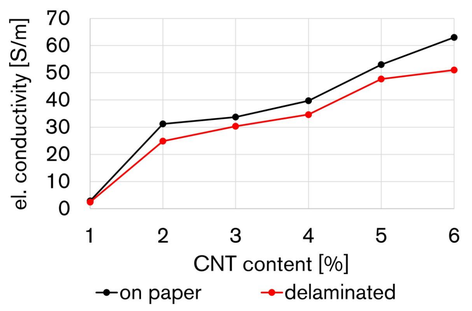
Properties of heatable coatings



Rheological behavior of CNT-containing dispersions of UP



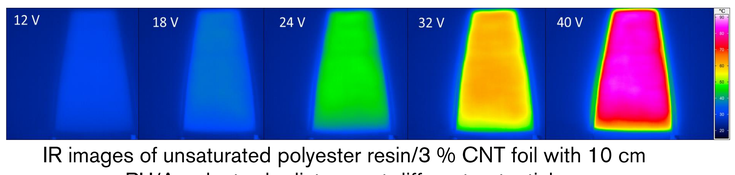
TGA of pure UP resin



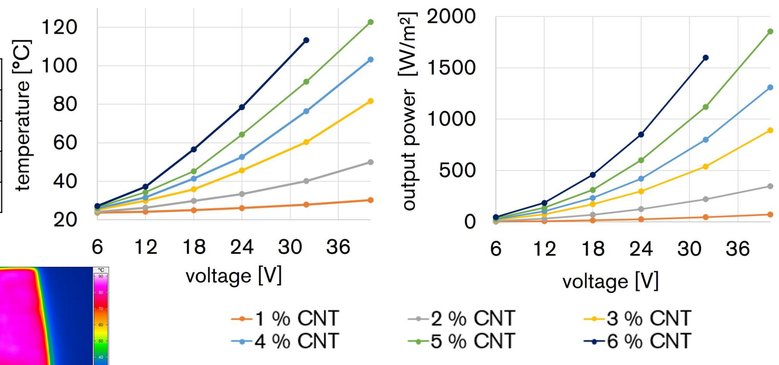
Electrical conductivity of the foils consisting of 3 layers

Mechanical characterisation of CNT-containing film (3 % CNT)

film thickness	171 ± 8 µm
tensile strength longitudinal	9,37 ± 1,63 N/mm²
tensile strength transverse	6,65 ± 1,44 N/mm²
elongation at break, longitudinal	6 ± 2 %
elongation at break, transverse	3 ± 1 %



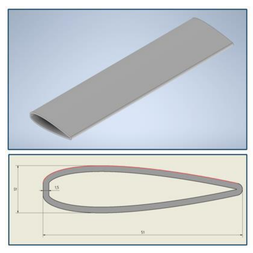
IR images of unsaturated polyester resin/3 % CNT foil with 10 cm PU/Ag-electrode distance at different potentials



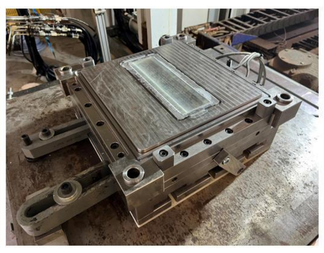
Increase in temperature and output power in dependance of the CNT concentrations and the applied voltage

Demonstrators for application

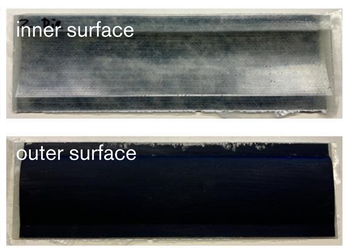
Embedding into rigid composite material: Pressing of NACA profiles



NACA wing structure

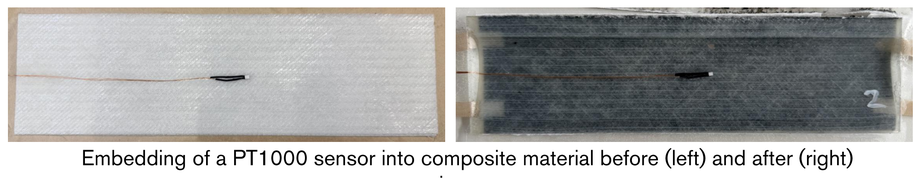


Pressing tool with lower mould plate and NACA component



Pressed NACA component with coating

Integration of sensors



Embedding of a PT1000 sensor into composite material before (left) and after (right) pressing process

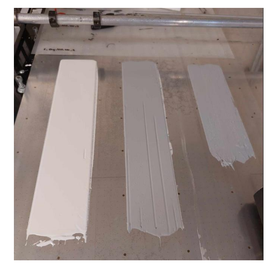
Initially, the wires were soldered to the sensor; the assembly was then integrated between the prepreg layers and securely consolidated during pressing.

Application of insulating top layer

Polyester gelcoat modified with organosilicon compounds was applied by air spraying or tape casting to enhance the hydrophobic and icephobic properties of the surface.

Effects of organosilicon compounds in the top layer

surface property	effect of modification
water contact angle	↑ 53 %
ice adhesion strength	↓ 52 %
freezing delay time	↑ 728 %



Tape casting

Testing in icing wind tunnel

- evaluation under different icing regimes (glaze, rime and mixed ice)
- controlled variation of air temperature, air velocity, liquid water content (LWC) and droplet size (MVD)
- assessment of ice accumulation



NACA profile in icing wind tunnel

Processing procedure for flexible composite material of UP in pilot scale



Roll-to-roll blade coating process and application of contacting lines

- reverse coating process on release paper
- 4 CNT-containing layers
- conductive lines: copper adhesive tape
- lamination with glass fibre nonwoven

Challenges:
- high viscosity, shear thinning behaviour of the paste
- curing process: sticky surface ↔ embrittlement

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