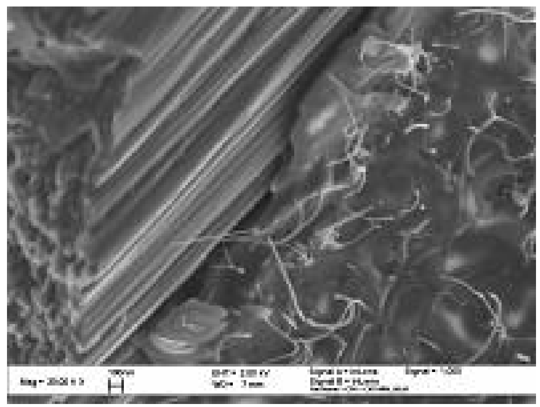
Carbon Nanotube Doped CFRP‘s - Challenge and Improvement for Space Structures?

7th ESA Round-Table on MNT for Space Applications



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High Performance Space Structure Systems GmbH

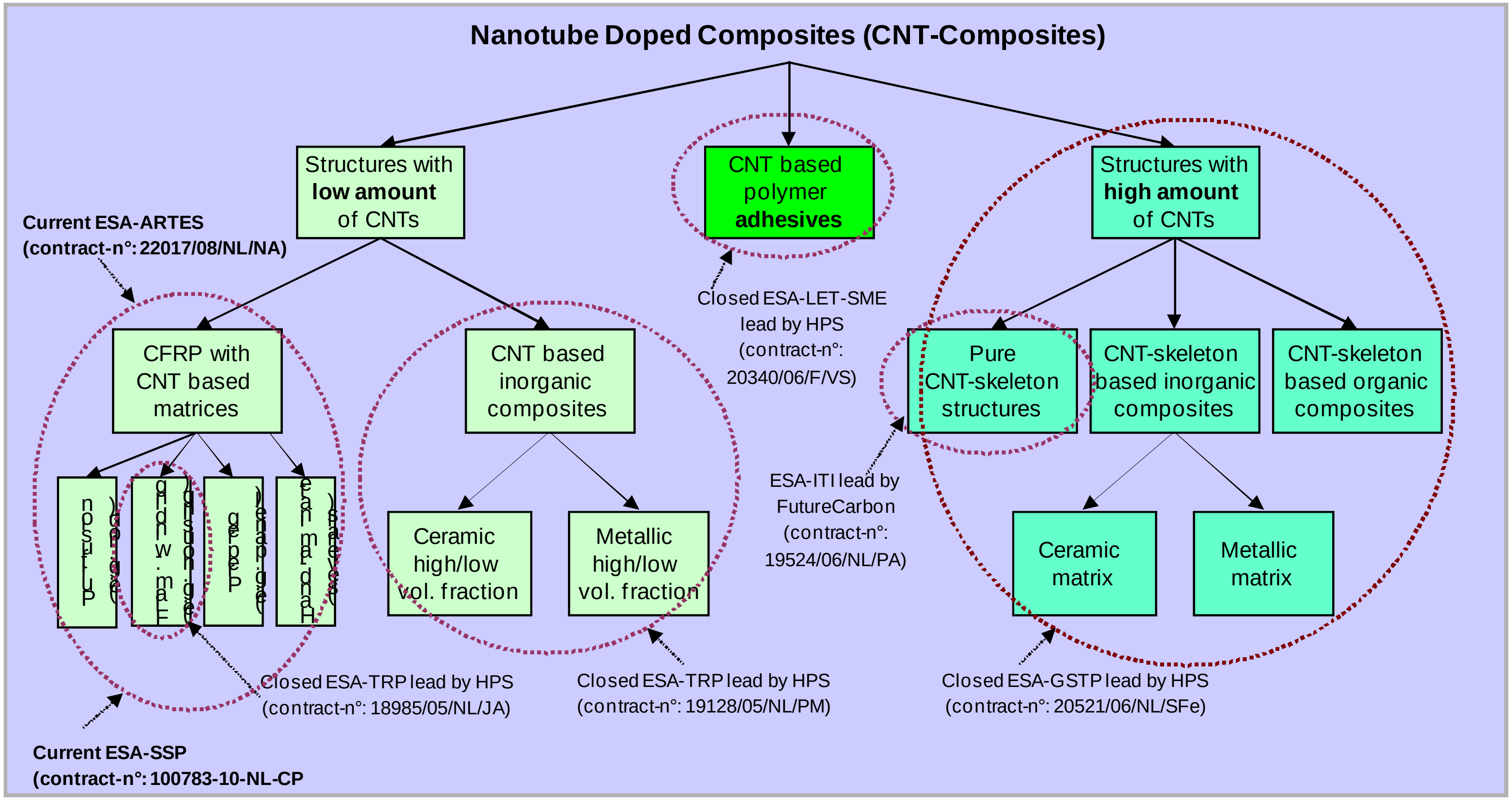
Motivation of CNT Doping

Why doping CFRP’s with CNT’s although cost increase is involved?

- Improvements in material behaviour can:
  - directly or indirectly reduce mass of current CFRP parts on spacecrafts
  - allow for the substitution of parts that are currently made from metals and other materials

- Reduction of mass allows e.g. for more payload (mass = money)

CNT Heritage Overview at HPS

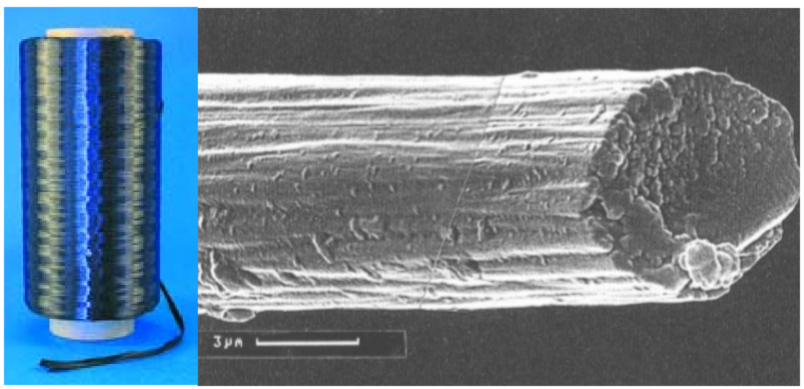


In this presentation only CNT-CFRP's are addressed.

CNT-CFRP

We call a CNT-CFRP when it consists of the following ingredients:

Carbon (reinforcing) fibres

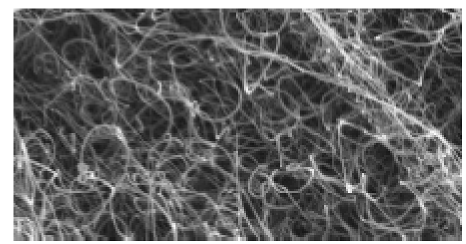


Left: carbon fibre roving bobbin
Right: single carbon fibre

Polymeric resin (system)

Epoxy resin

Nano dopant: CNT

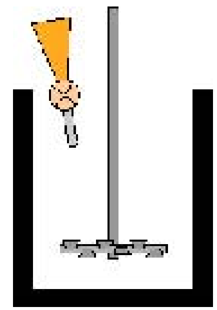


CNT network

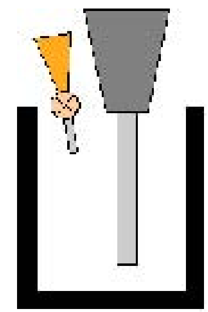
CNT-Resin Production

Depending on the ingredients and on the targeted CNT-resin viscosity different processes are suitable or a combination of them:

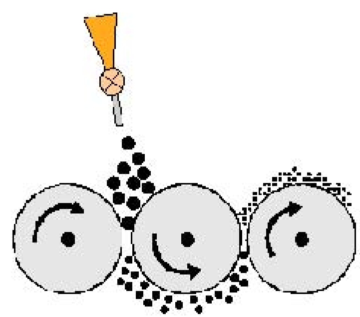
- Dissolver
- Ultra sonic
- Roll (single, multiple)
- Centrifuge (single, multiple)
- Etc.



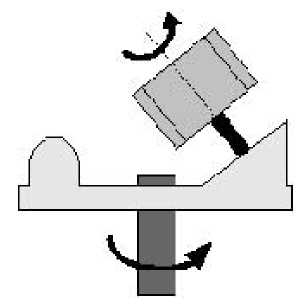
Dissolver



Ultra sonic



(Multiple) roll



(multiple) Centrifuge

Images by FutureCarbon

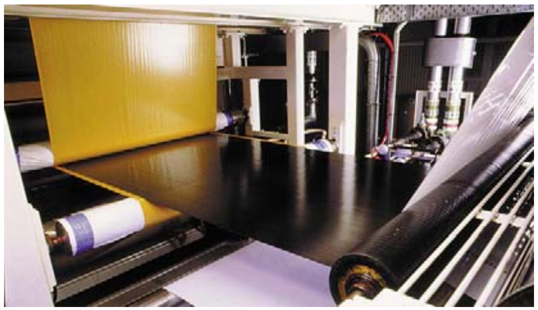
Specimen Production

Different CNT-CFRP manufacturing techniques were explored:

- Hand laminate, vacuum assisted
- RTM
- "Small scale" pre-pregging
- "Industrial scale" pre-pregging
- Winding
- Pultrusion

CNT-CFRP winding at Invent

CNT-CFRP pultrusion at Inegi (lab scale)

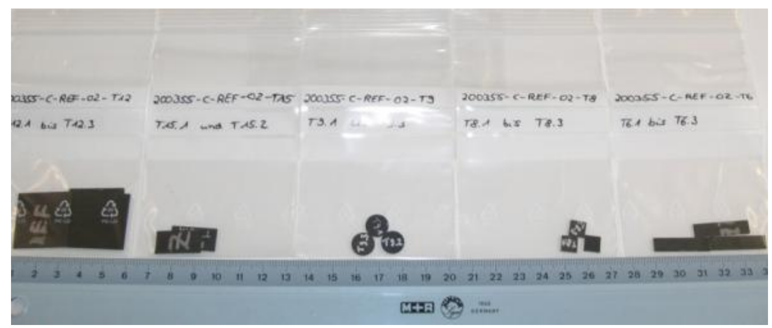


Prepreg prodcution

Investigations and Testing

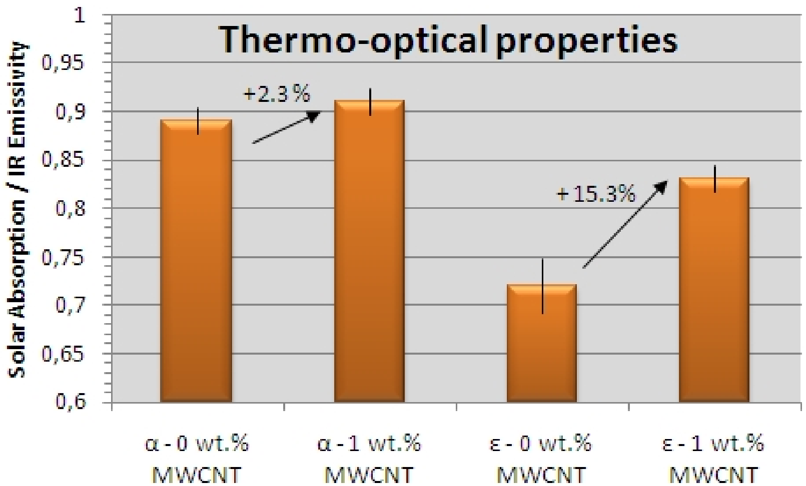
CFRP characteristics investigated:

- Thermal conductivity
- Electrical resistance
- Mechanical strength (statically testing)
- Optical and infrared properties
- Radio frequency characteristics
- Thermal expansion behaviour
- Moisture expansion behaviour
- Glass transition temperature
- Preceding microscopic investigations and subsequent SEM investigations

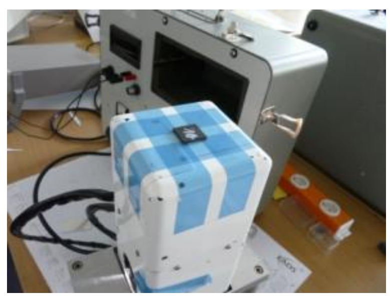


Outline of project COPE samples
- on the whole several hundred specimens -

Results –Thermo-optical Properties



Solar absorption and infrared emissivity measured acc. to ECSS-Q-ST-70-09C



Test apparatus Gier Dunkle DB100 / Gier Dunkle MS251 of Astrium Ottobrunn

- All present tests with different ingredients show a high increase of infrared emissivity (ε), i.e. approx.10% - 19%

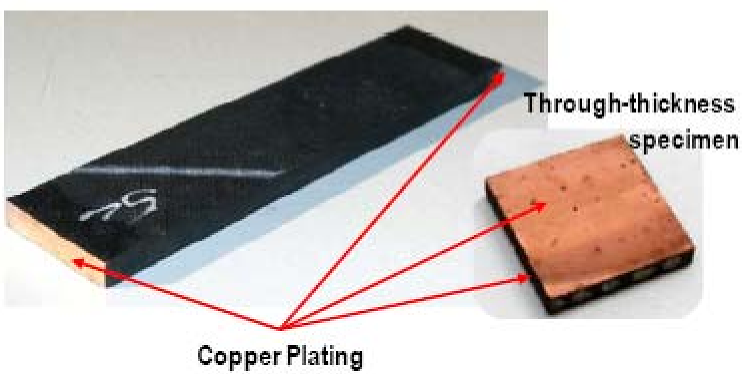
- Only minor increase in solar absorption

→Radiator application?

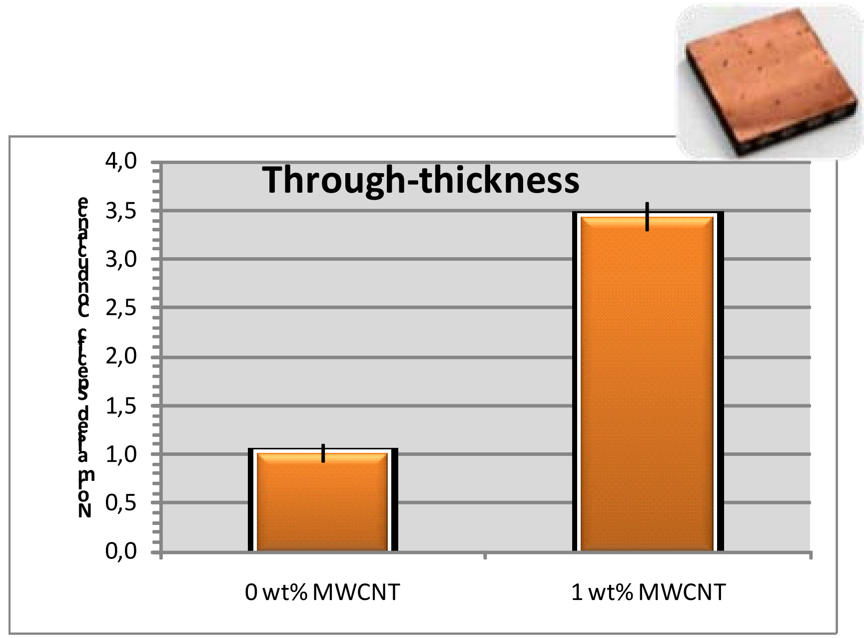
- 1wt.% as-produced MW-CNT but also other filler fractions were examined

Results – Electrical Conductivity

- Fibre in-plane electrical conductivity could not been improved significantly
- Transverse electrical conductivity could be improved by a factor of approx. 2 - 4



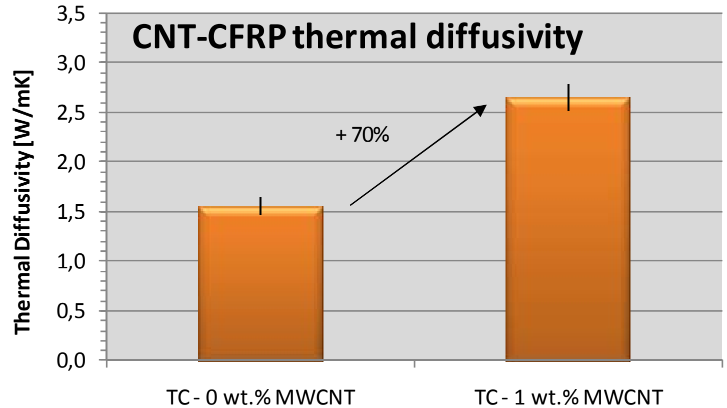
Specimens for resistance measurements

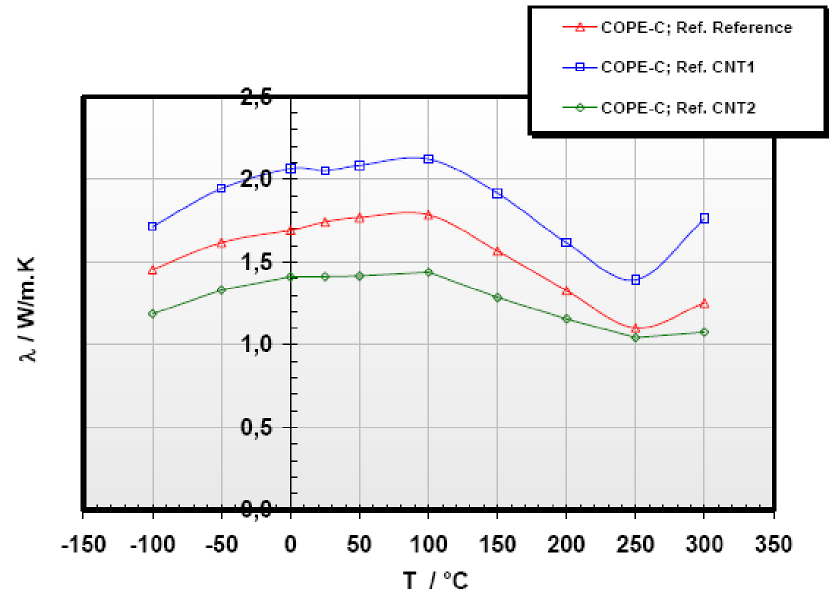


Normalised specific conductance of 1 exemplary CNT-CFRP material combination (UHM & epoxy) and its reference

Results – Thermal Conductivity

- CNT-CFRP fibre in-plane thermal conductivity not determined due to low importance (C-fibre dominated property).
- Transverse thermal conductivity could be improved by up to approx. 100%
- Also degradation in thermal conductivity observed, potential reason: decreased FVF.



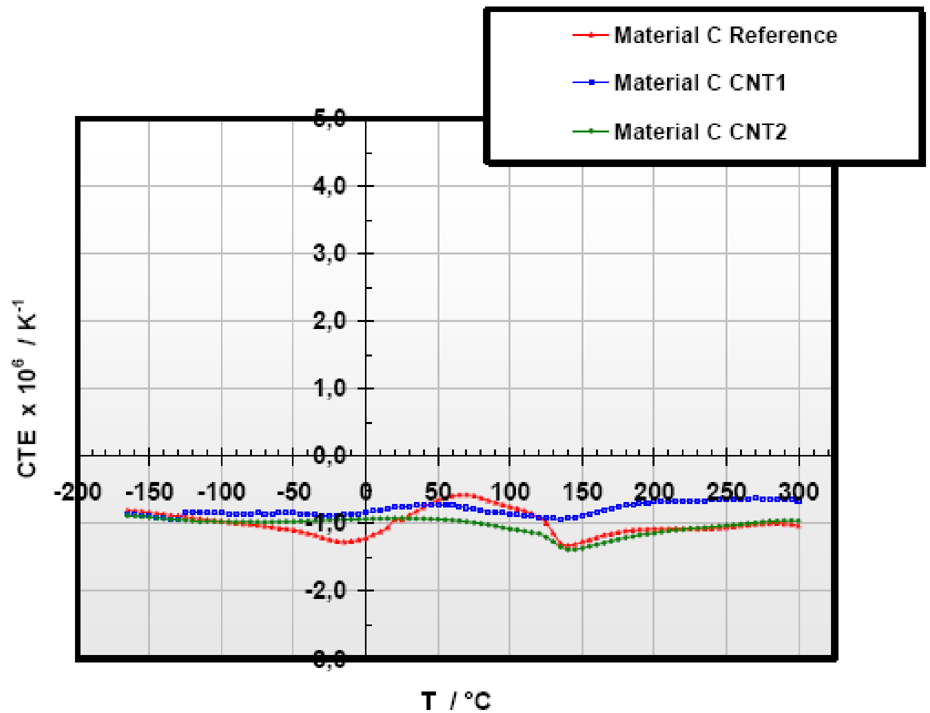


Thermal conductivity of different CNT-CFRP materials

Results – Coefficient of Thermal Expansion (CTE)

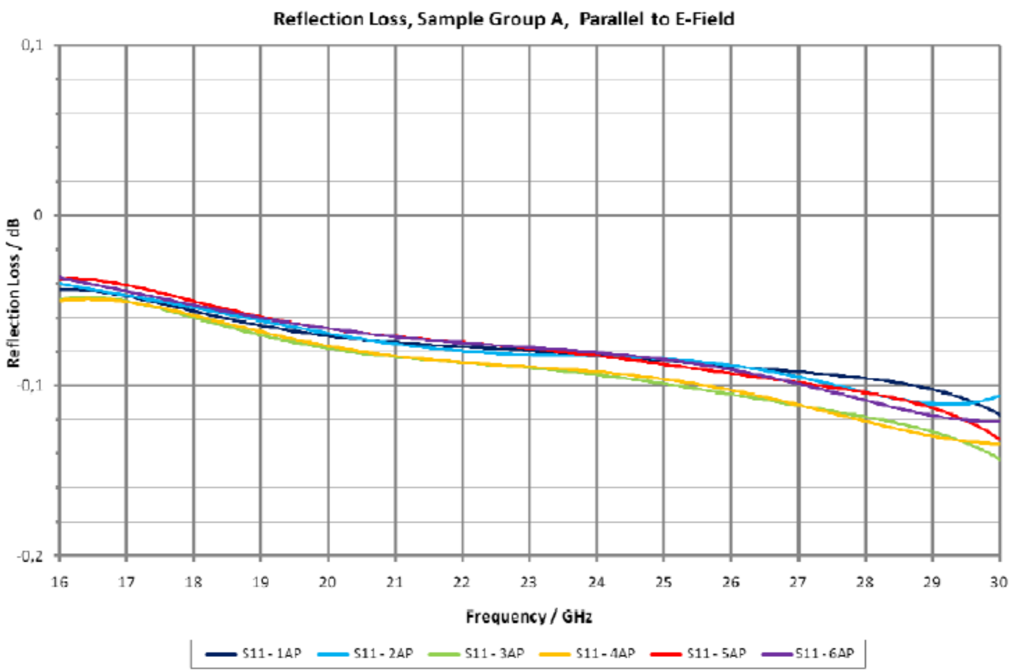
- CTE of tested materials yield the following results:
  - slight increase
  - slight decrease
  - no significant change (see graph, material CNT2 and its reference)

- CTE of tested CNT materials show no apparent trend



CTE measurements at AIT for one specific material and its CNT variations

Results – Radio Frequency Testing



Representative for RF properties, i.e. reflection loss

Scope of testing:

- Ku-band up to Ka-band (16-30GHz)
- Reflection Loss (S11)
- Amplitude Variation ΔA for orthogonal polarizations
- Phase Variation ΔP for orthogonal polarizations
- Depolarization
- Transmission Loss (S21)

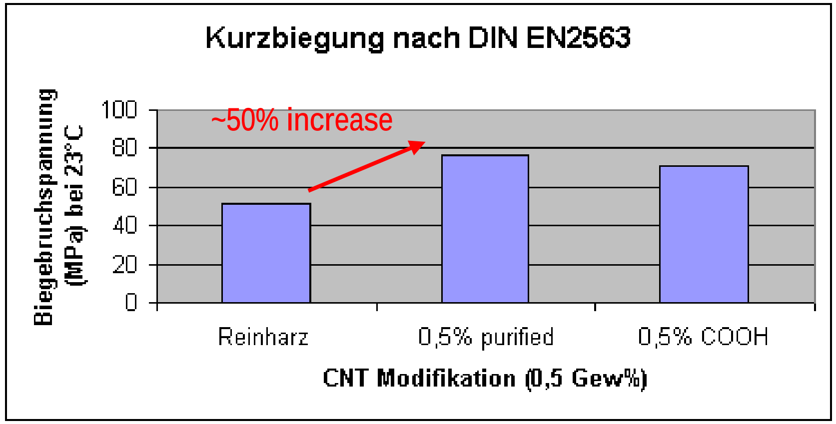
No major impact on RF properties due to CNT doping observed.

Results – Mechanical Strength

Reference test for mechanical strength and laminate quality:

- ILSS acc. to EN 2563

- High scattering of results, i.e. some materials show improvement (see right side) some show decline in ILSS
- Results appear to correspond to manufacturing process
- Good results for pultrusion and winding (see figure on right side)



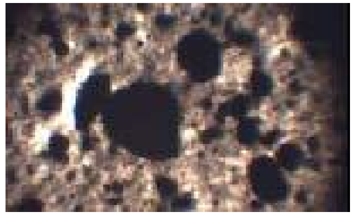
Representative for mechanical properties, i.e. ILSS
- Results for Invent made "fibre wound pre-prepregs"

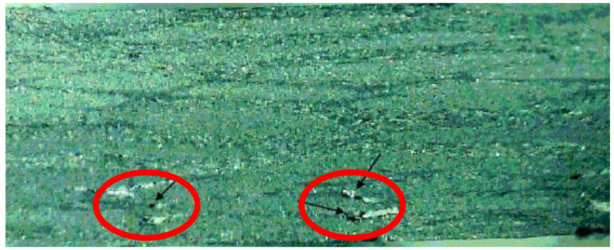
These results are obtained within an German funded project using resources of the German Federal Ministry of Economics and Technology, support code 03X0051C

Encountered Problems

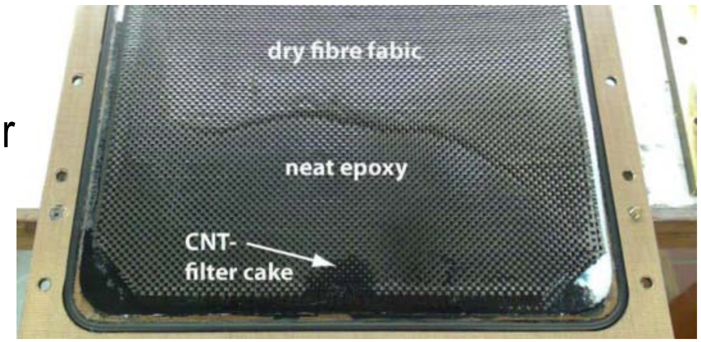
- High variety in ingredients
  - CNT's (e.g. as-produced, purified, processing, number of walls, aspect ratio, etc.)
  - Fibres (HT, IM, HM, UHM etc.)
  - Resins (epoxies, cyanate esters etc.)
- Variation CNT dispersion quality in resin systems (agglomerations etc.)
- Increase of viscosity prohibits some manufacturing techniques
- Filter effects prohibits the use of RTM manufacturing at reasonable fibre volume fractions, i.e. approx. 50% and higher
- For the moment unexplainable variations in test results → reproducibility problem
- Health aspects require special handling

CNT-resin microscopic image of Invent





CNT-CFRP cross-section polish with distributed pores



Sample plate produced at TU Hamburg-Harburg

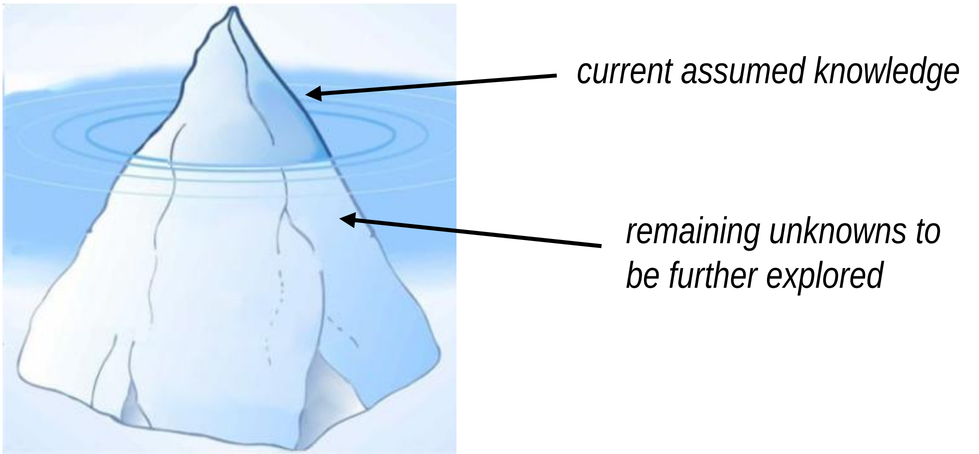
Conclusions

- On first sight some results are somewhat “disappointing” since either only slight improvements were observed or sometimes even a degradation was observed

  → Too high expectations?
- However also good and pleasant improvement results are found – future activities should aim for their further enhancement
- Manufacturing techniques are of high importance and determine the final CNT-CFRP characteristics
- There are favourable combinations of the ingredients (CNT/resin/fibre) and favourable manufacturing processes: pultrusion & winding
- Reproducibility trouble

Conclusions – cont'd

- First steps of upscaling of CNT-CFRP manufacturing accomplished (prepreg)
- Mechanisms of CNT's inside the CFRP have to be investigated fundamentally



- Currently, we can only see the top of the iceberg → Target: further research!

Future Prospects

- Fundamental research of mechanisms required
- Only “primary” characteristics were examined. However, “secondary” characteristics are also of high importance such as:
  - Machinability
  - Adhesion of coatings and adhesives
  - Ageing resistance
  - Dynamical performance
  - Micro fracture resistance, already observed: less micro crack propagation & brittleness
  - Etc.
- Determination of appropriate material combinations (e.g. 5 fibre types, 5 matrices, 5 CNT’s, 3 different filler volume fractions already yield a tremendous amount of testing)
- Establishment of qualified manufacturing processes and their enhancement

Acknowledgments

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