NANOTECHNOLOGIES FOR COMPOSITE STRUCTURES

From Nanocomposites To Multifunctional Nano-Enabled Fibre Reinforced Composites For Spacecrafts

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AML/UoP

- In operation since **1980**
- Part of the Department of Mechanical Engineering and Aeronautics/ University of Patras, Greece
- General field of research: ***MATERIALS & STRUCTURES***
- Focused research topic: science, technology and applications of **COMPOSITE MATERIALS**
- Four major R&D groups:
  - **Materials & Processes Development**
  - **Non Destructive Inspection & Structural Health Monitoring**
  - **Design & Analysis of Advanced Structures**
  - **Testing & Materials Characterization**
- More than 380 Journal Publications, 500 Conference Presentations and 9 Published Volumes
- Involvement in over **30** EU/ESA or Industry R&D projects

APPLIED MECHANICS LABORATORY
University of Patras, Greece
Department of Mechanical Engineering & Aeronautics

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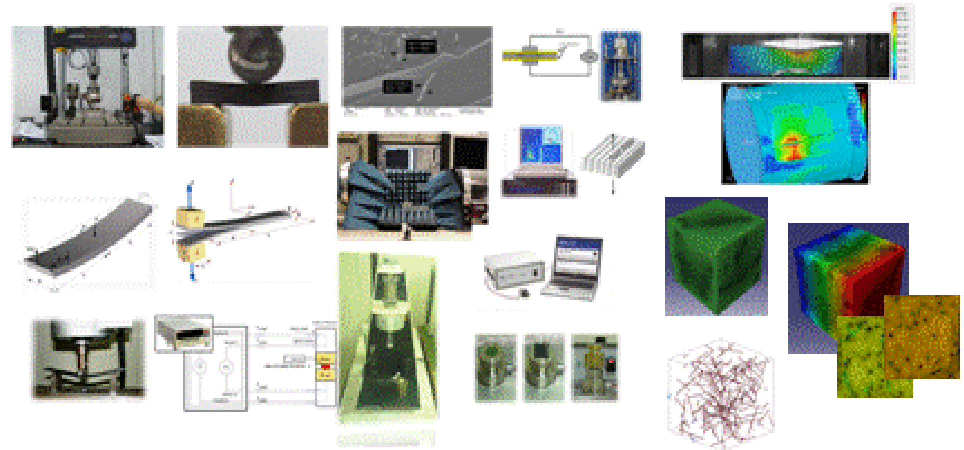
UNIVERSITY OF PATRAS
GREECE (HELLAS)



esa
SEVENTH FRAMEWORK PROGRAMME
SIXTH FRAMEWORK PROGRAMME
NSF

1. ESA-GSTP-(2013-2014) NAFO: Use of Nanocomposite reinforced Foams for Manufacture of Superlightweight Stiff Sandwich Panels
2. ESA-GTF-(2012-2015) NANO-2: Design, Development, Manufacturing and Process Monitoring for structures of nano-modified multifunctional pre-preg materials targeting near term space applications.
3. ESA-GSTP-(2011-2013) NACO-2: Non-conventional Matrix / CNT Reinforced Composites for Applications in Space - 2.
4. EU-FP7-SPACE-(2011-2014) DEORBIT-SAIL: De-Orbiting of Satellites using Solar Sails
5. ESA-NPI-(2009-2011) MINERVA: Methodology for Innovative Health Monitoring of Aerospace structures using dynamic response measurements and advanced signal process.
6. ESA-TRP-(2010-2011) NAREMA: Nanotube Reinforced Structural Materials for Spacecraft Applications.
7. ESA-TRP-(2009-2010) DELAT: Delamination Assessment Tool for Composite Structures.
8. ESA-GTF-(2008-2009) NANO: Nano-modified fiber reinforced polymers in terms of mechanical, electrical and thermal properties towards the development of new materials for space applications.
9. ESA-GSTP-(2007-2009) NACO: Non-conventional Matrix / CNT Reinforced Composites for Applications in Space.
10. ESA-EDU-(2004-2007) YES2: Second Young Engineers Satellite Project. University of Patras YES2 Mechanical Center of Expertise.

- AML/UoP is member of the University of Patras Cube-sat QB50 Team (UPSAT)

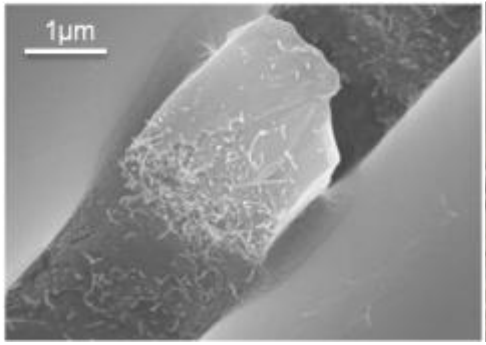
Adamant Composites Ltd.

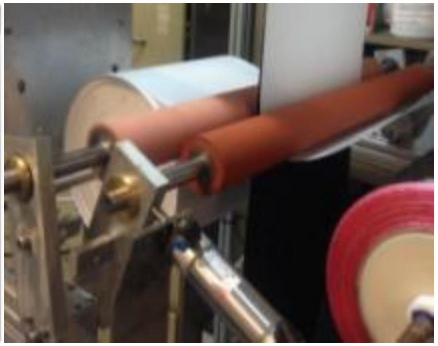
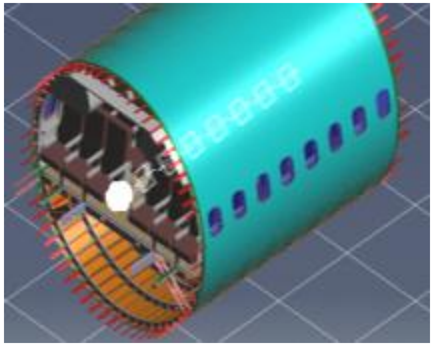
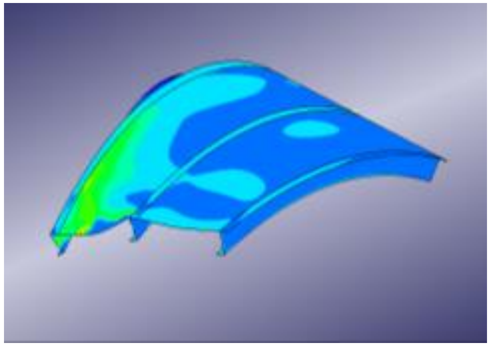
ADAMANT COMPOSITES

- Young SME company
- Founded in 2012
- Based in Patras, Greece
- Highly experienced mechanical and aeronautics engineers

- Competences
  - Multi-scale reinforced Composites
  - Composites Processing and Manufacturing
  - Engineering Design and Analysis

www.adamant-composites.gr



Overview of presentation

- Systemic approach of nano-reinforcement
- Review of implementation approaches for nano-reinforcement of composites
- Up-scaling strategies towards final structures
- Modeling capabilities for nano-reinforced composites

Starting point

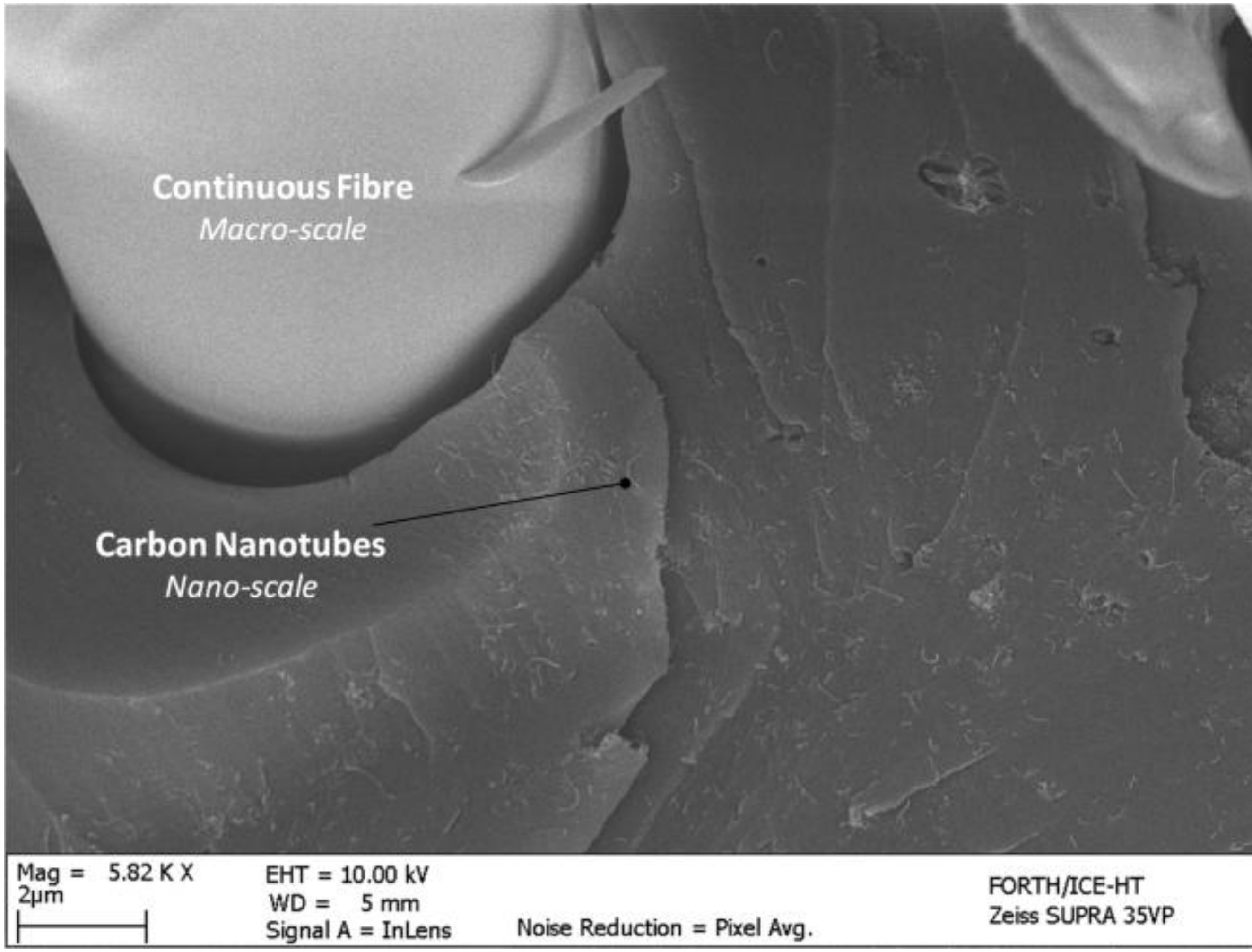
- Nano-composites have been around already since the ‘90s (e.g. carbon black)
- CNT gave a boost to research of nano-composites

<u>The tipping point</u>

Nano-modification of FRP matrix

Multi-Scale Composites

Multi-Scale Composites



Use of nanotechnology *For structural applications*

- **Nano-augmentation**
  - augment existing or new materials with nanomaterials with significantly enhanced properties for improvement of the structural and functional performance, and therefore reduction of structural weight and cost
- **Nano-engineering**
  - targeted use of different nanomaterials
- **Nano-enabling**
  - Nano-only

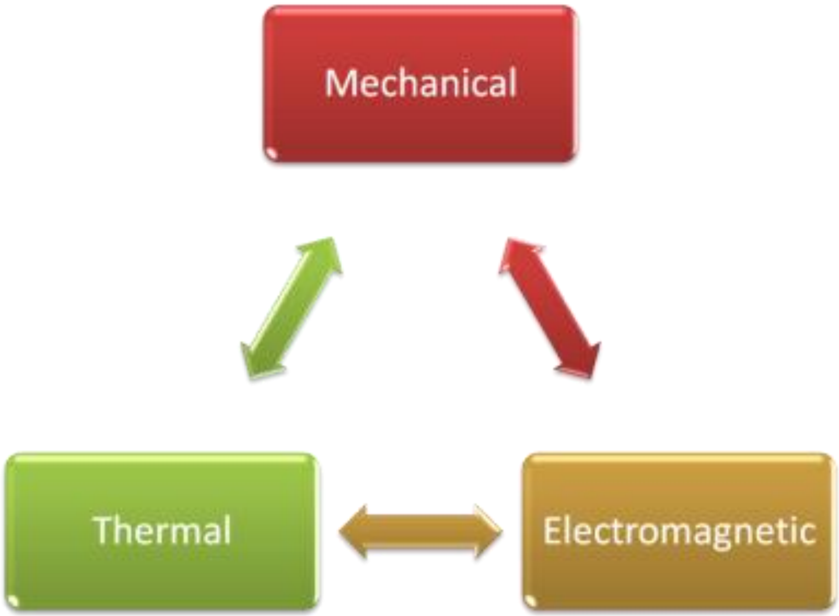
Edelman et al. Nanocomposites for Future Airbus Airframes, October 2008

Background Questions

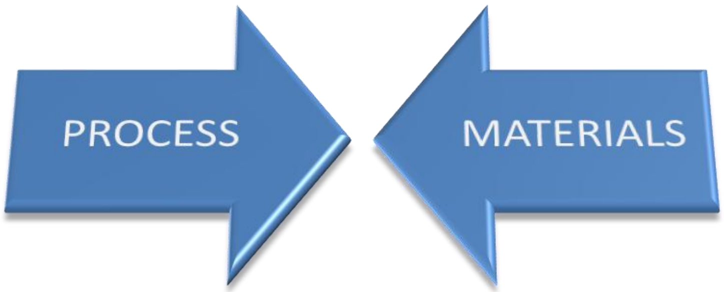
- Progress has been made, but where do we stand after >10 years?
- What do the end-users see and say?
- Focus is on structural nano-composites

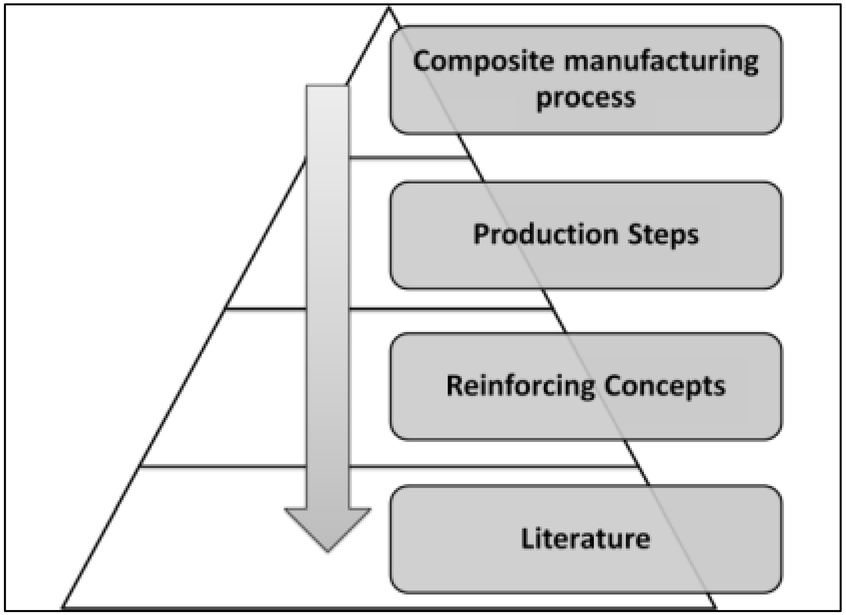
Framework of presentation

- Structural Composites: E > 10GPa, σ > 50MPa
- Fibrous composites → Manufacturing methods
- Review from the manufacturing perspective
- Multi-functional performance

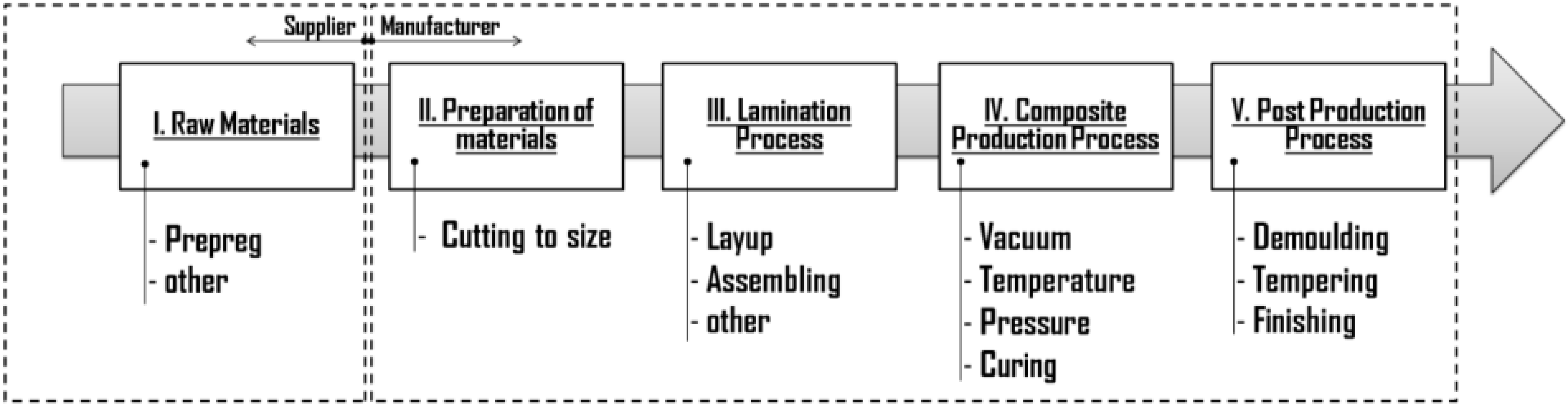


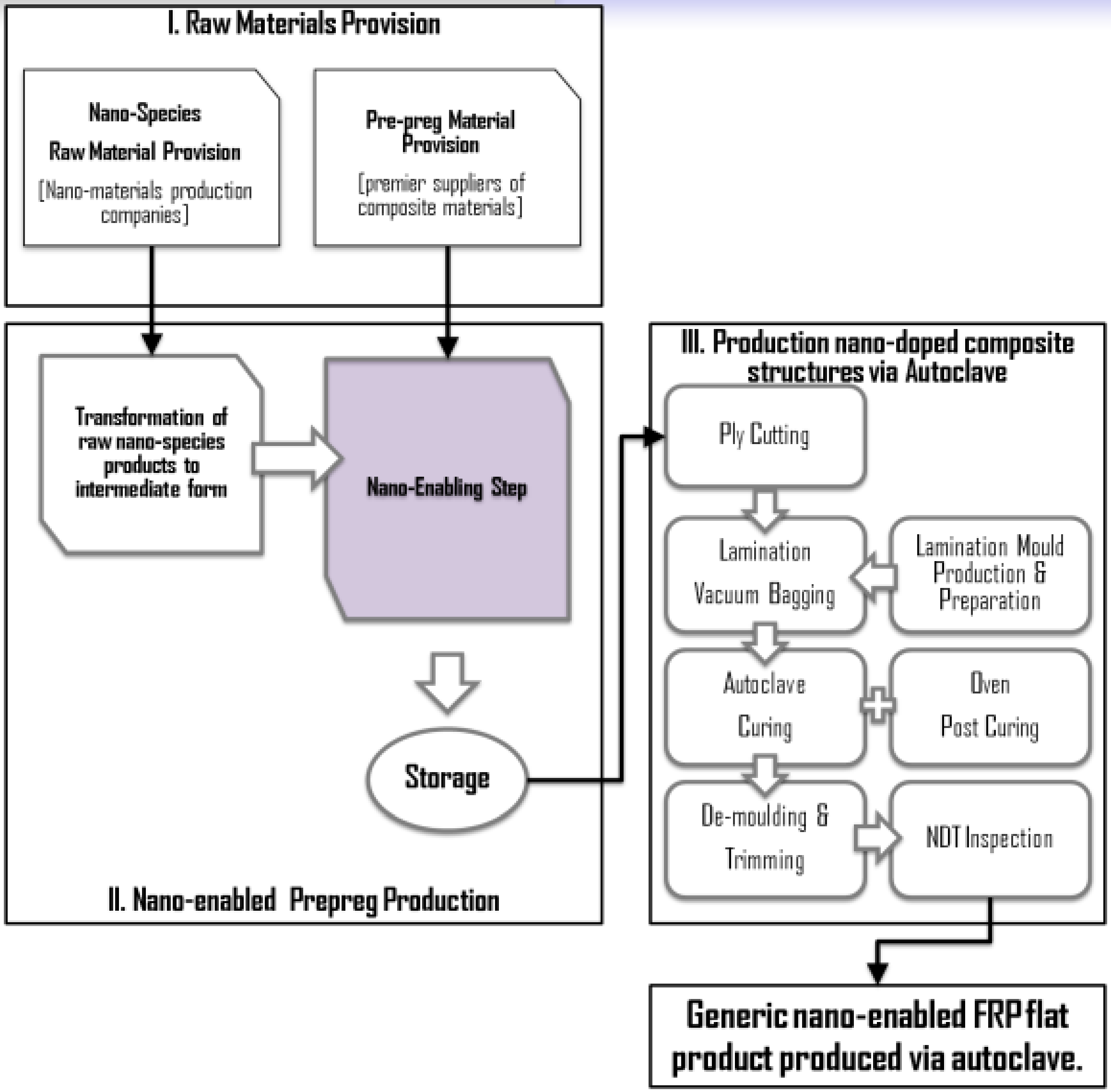
- State-of-the-Art Approach
  - PROCESS
    - AC/prepreg process
    - Infusion-based/RTM processes
  - MATERIAL
    - Nano-materials used in literature for what property ?
      - Electrical
      - Thermal
      - Mechanical
      - Damping
      - Etc.



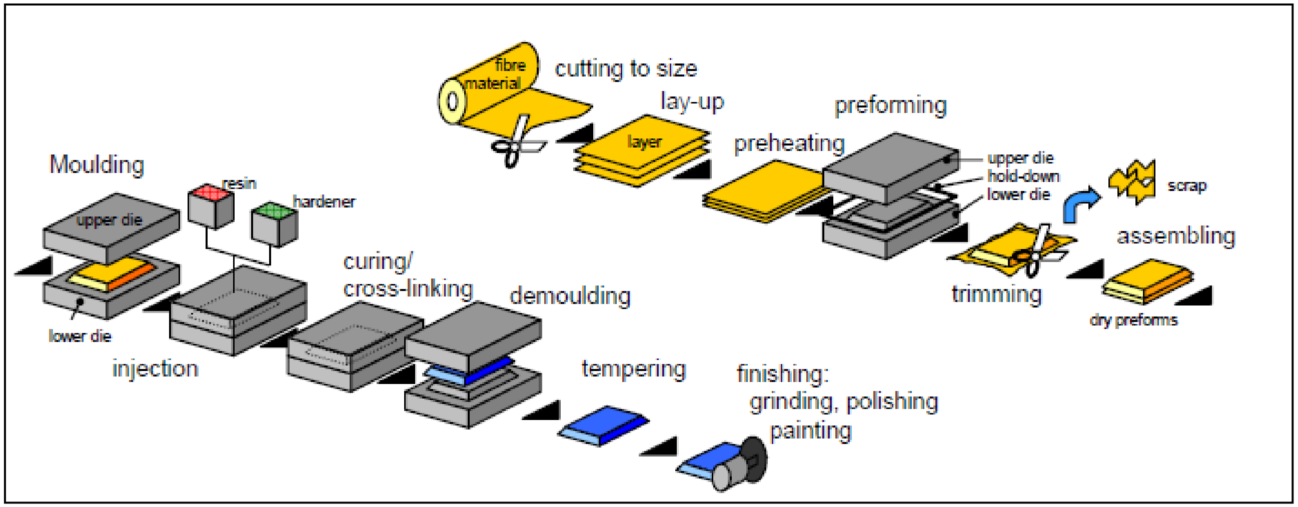


- Prepreg/Autoclave conventional process




I. Raw Materials Provision
Nano-Species Raw Material Provision
[Nano-materials production companies]
Pre-preg Material Provision
[premier suppliers of composite materials]
Transformation of raw nano-species products to intermediate form
Nano-Enabling Step
Storage
II. Nano-enabled Prepreg Production
III. Production nano-doped composite structures via Autoclave
Ply Cutting
Lamination Vacuum Bagging
Lamination Mould Production & Preparation
Autoclave Curing
Oven Post Curing
De-moulding & Trimming
NDT Inspection
Generic nano-enabled FRP flat product produced via autoclave.

State-of-the-Art *For Resin Transfer Techniques*



I. Raw Materials
- Fabrics
- Resin
- Hardener
- other

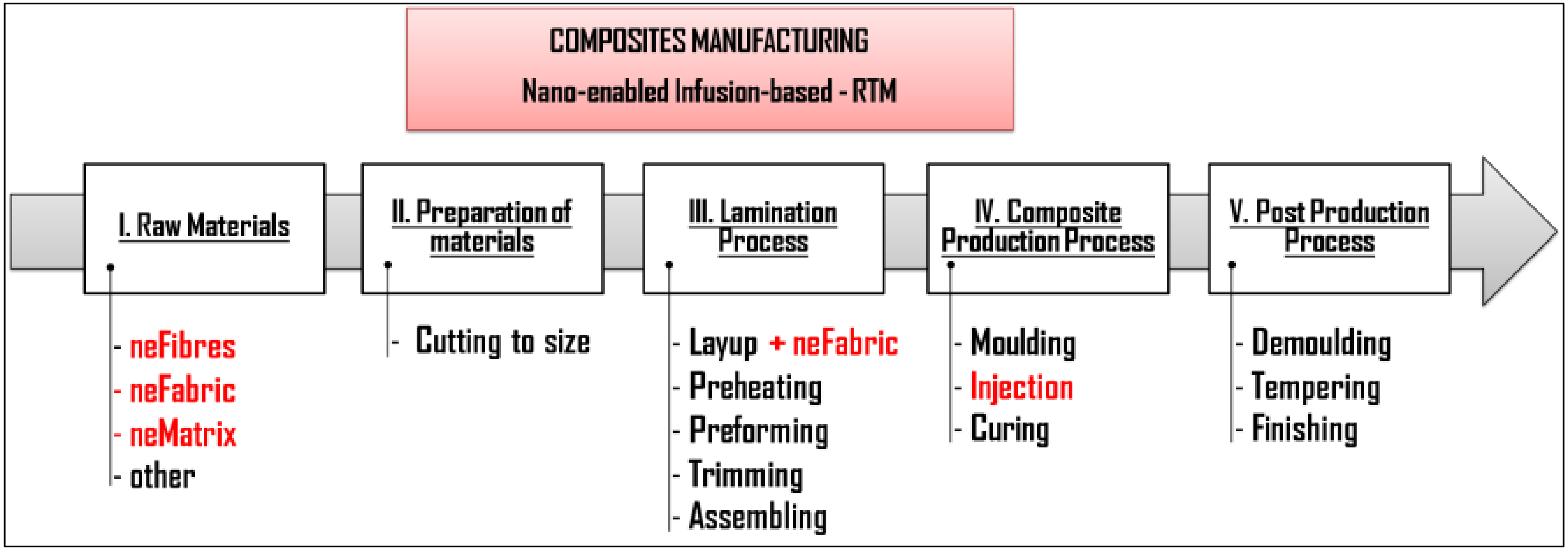
II. Preparation of materials
- Cutting to size

III. Lamination Process
- Layup
- Preheating
- Preforming
- Trimming
- Assembling

IV. Composite Production Process
- Moulding
- Injection
- Curing

V. Post Production Process
- Demoulding
- Tempering
- Finishing

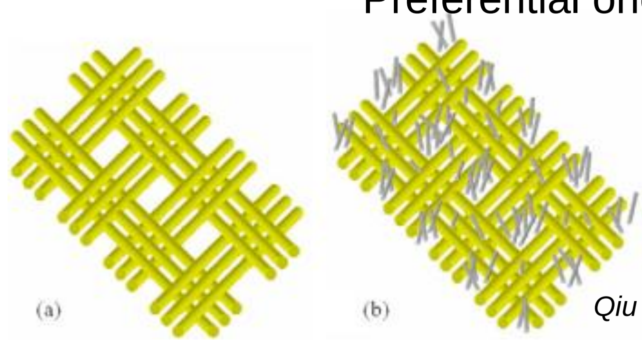
- Nano-Enabled FRPs through Resin Transfer



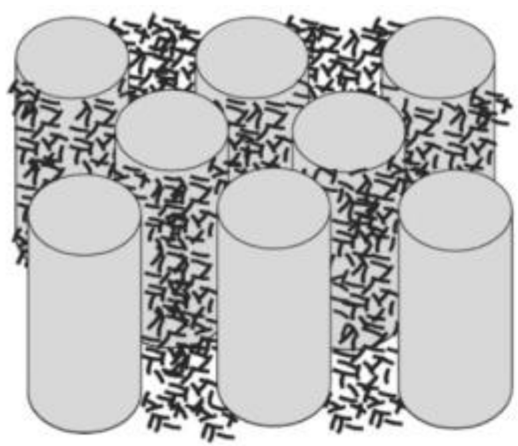
Approaches for nano-augmentation

Bulk matrix modification

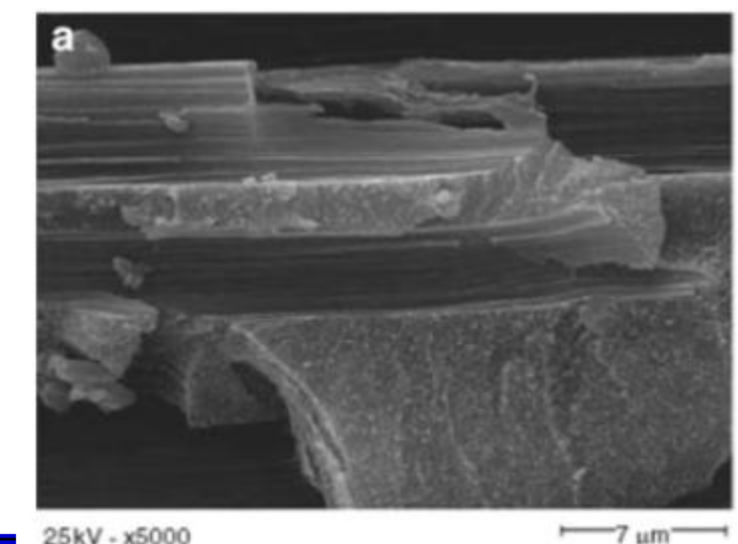
NANO-AUGMENTING ELEMENT	APPROACH	SCHEMATIC EXPLANATION
Matrix	Nano-doped resin	Preferential orientation through thickness



Qiu et al. Nanotechnology 18 (2007) 275708



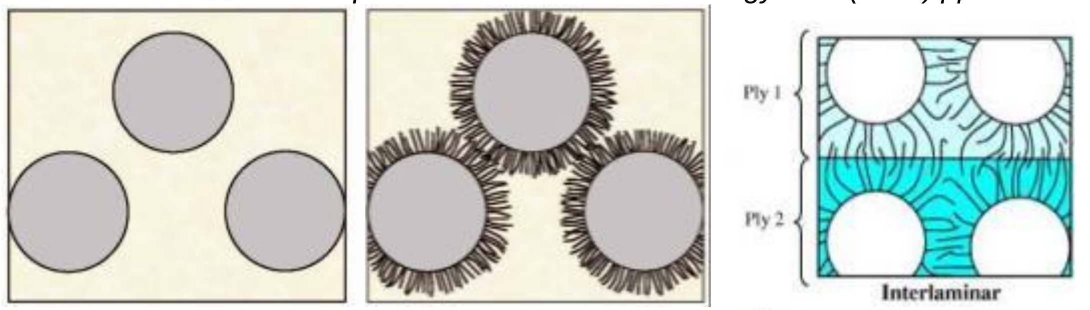
Vlasveld et al. Polymer 46(23), 10269–10278 (2005)

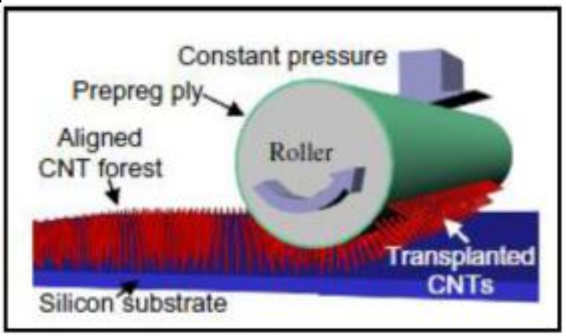


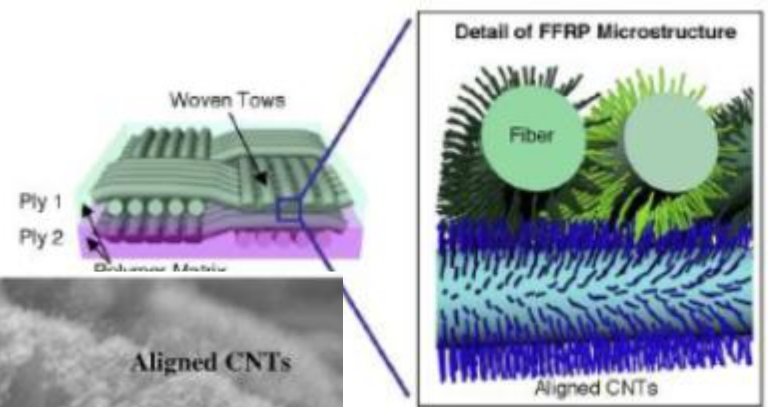
Approaches for nano-augmentation

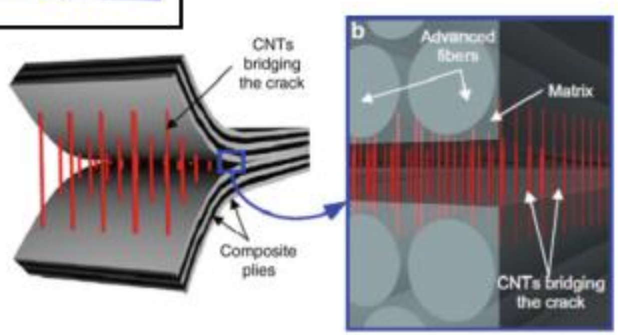
Targeted growth of CNT

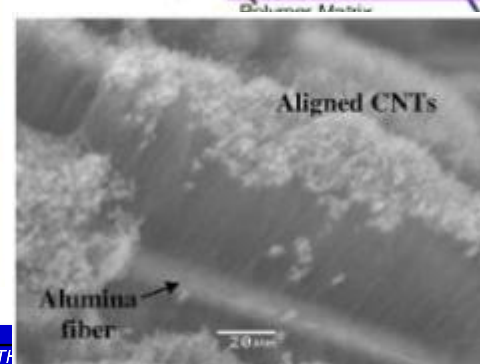
NANO-AUGMENTING ELEMENT	APPROACH	SCHEMATIC EXPLANATION
Fabric	Nano-doped fabric, Nano-reinforcement grown on fabric, Transplanted	*Wicks et al. Composites Science and Technology 70 1 (2010) pp. 20-28.*







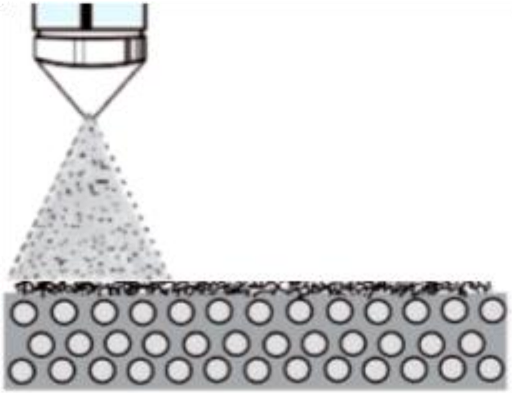
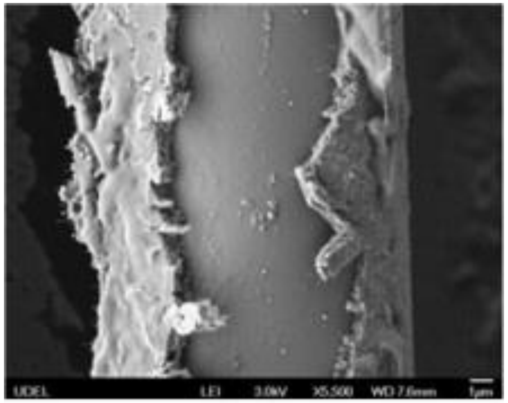




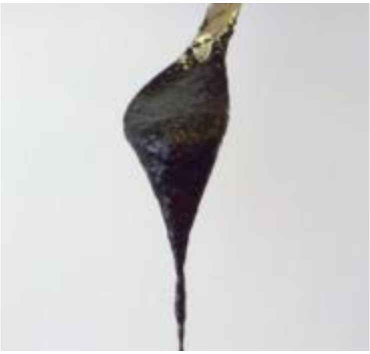
Garcia et al. Compos. Part A: Appl. Sci. Manuf. 39(6), 1065–1070 (2008).

Approaches for nano-augmentation

Other techniques

NANO-AUGMENTING ELEMENT	APPROACH	SCHEMATIC EXPLANATION
Matrix/ Laminate Interlayer	Nano-doped liquid (resin or solvent), Spray coating or Printing	 
Fabric	Nano-doped fibre sizing	

Approaches for nano-augmentation *Other techniques*

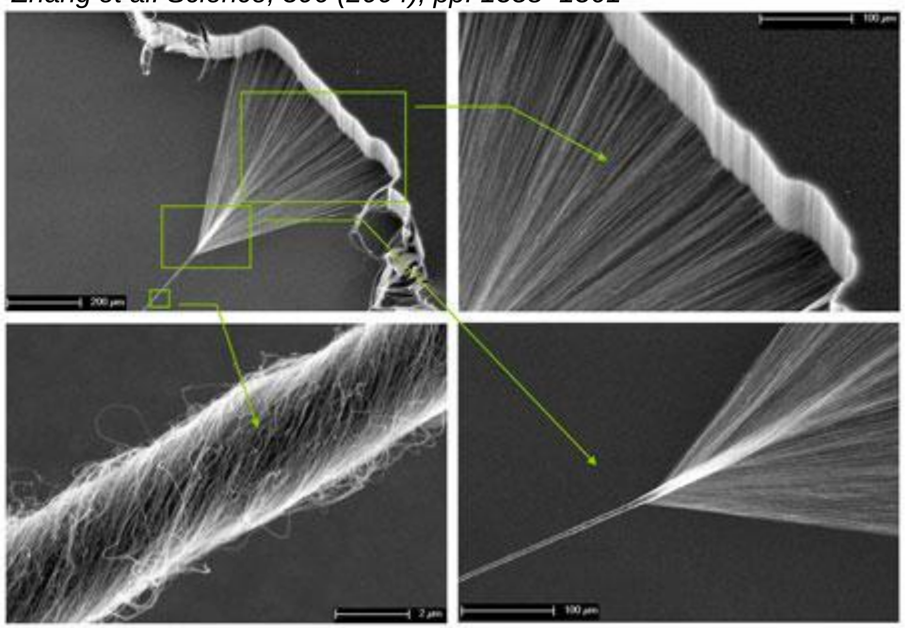
NANO-AUGMENTING ELEMENT	APPROACH	SCHEMATIC EXPLANATION
Matrix/Laminate Interlayer	Nano-filled polymer particles, Dry nano-particles	 
Laminate Interlayer	Nano-doped slurry/paste for Filming	 

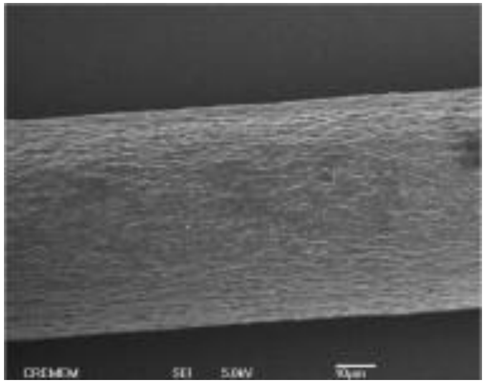
Approaches for nano-augmentation

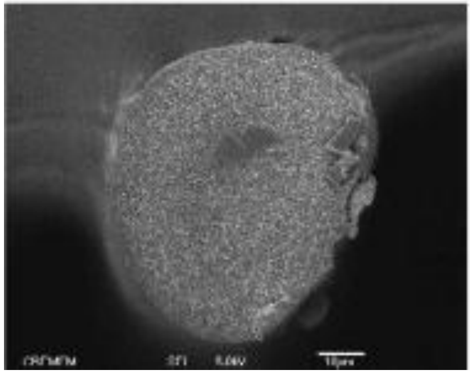
Nano-augmented fibres

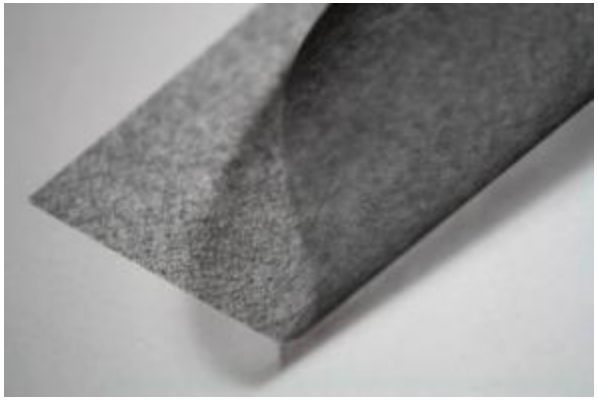
NANO-AUGMENTING ELEMENT	APPROACH	SCHEMATIC EXPLANATION
Laminate Interlayer	Nano-doped polymer fibre in fabric/veil form	

Zhang et al. Science, 306 (2004), pp. 1358–1361







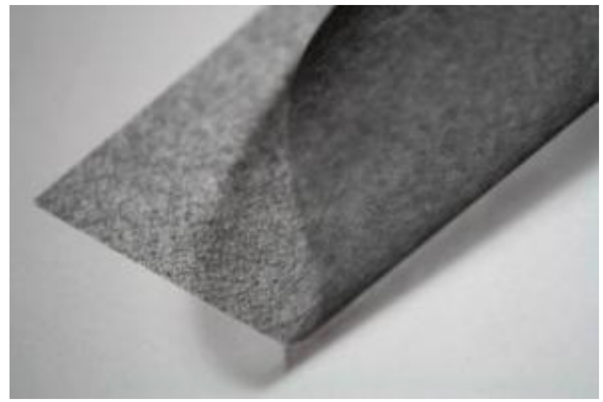


TFP

Approaches for nano-augmentation

Nano-augmented fabrics

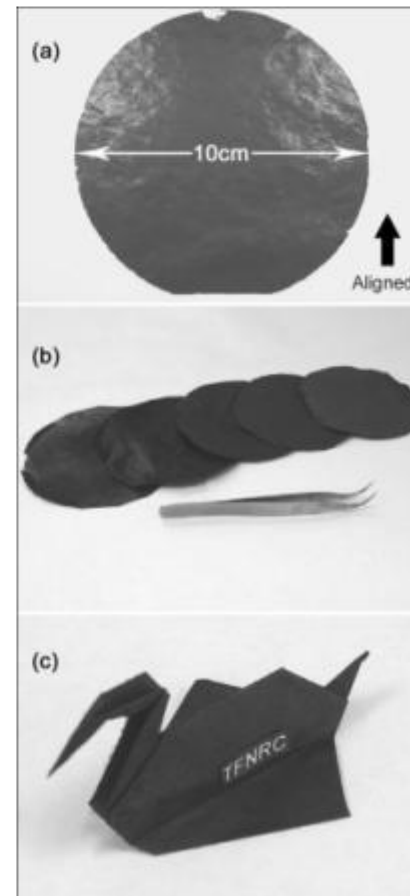
NANO-AUGMENTING ELEMENT	APPROACH	SCHEMATIC EXPLANATION
Fabric / Laminate Interlayer	3D microstructure/ preform of nano-particles **(**Buckypaper)	



TFP

Buckeye composites

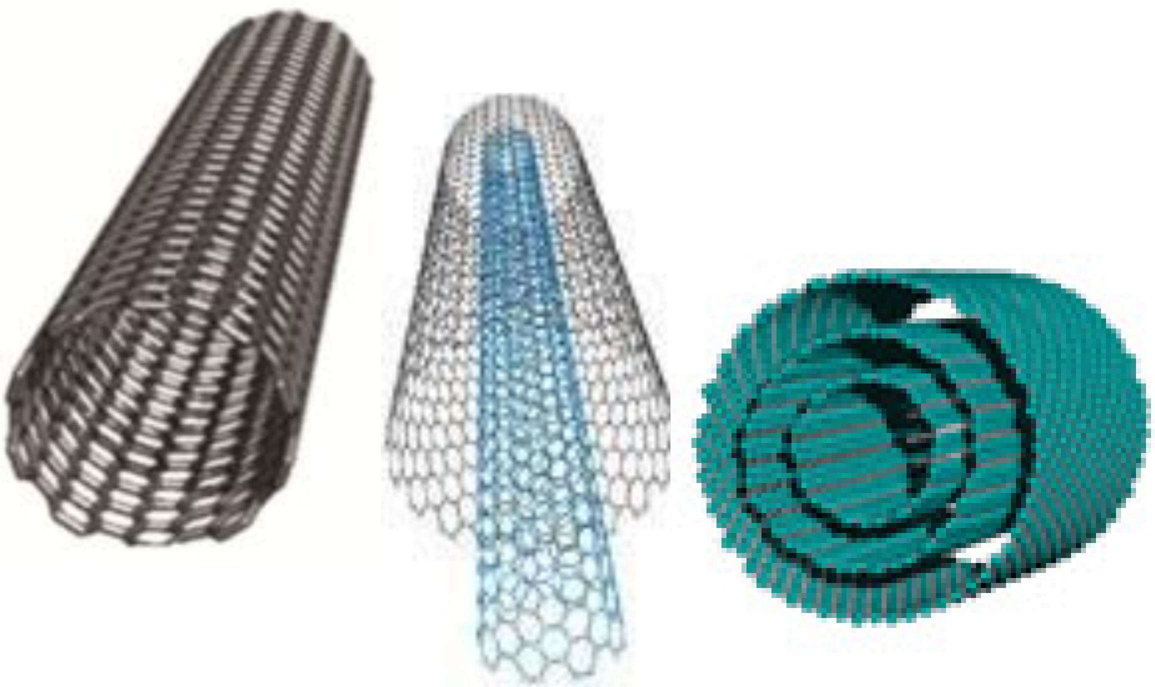
Florida State University

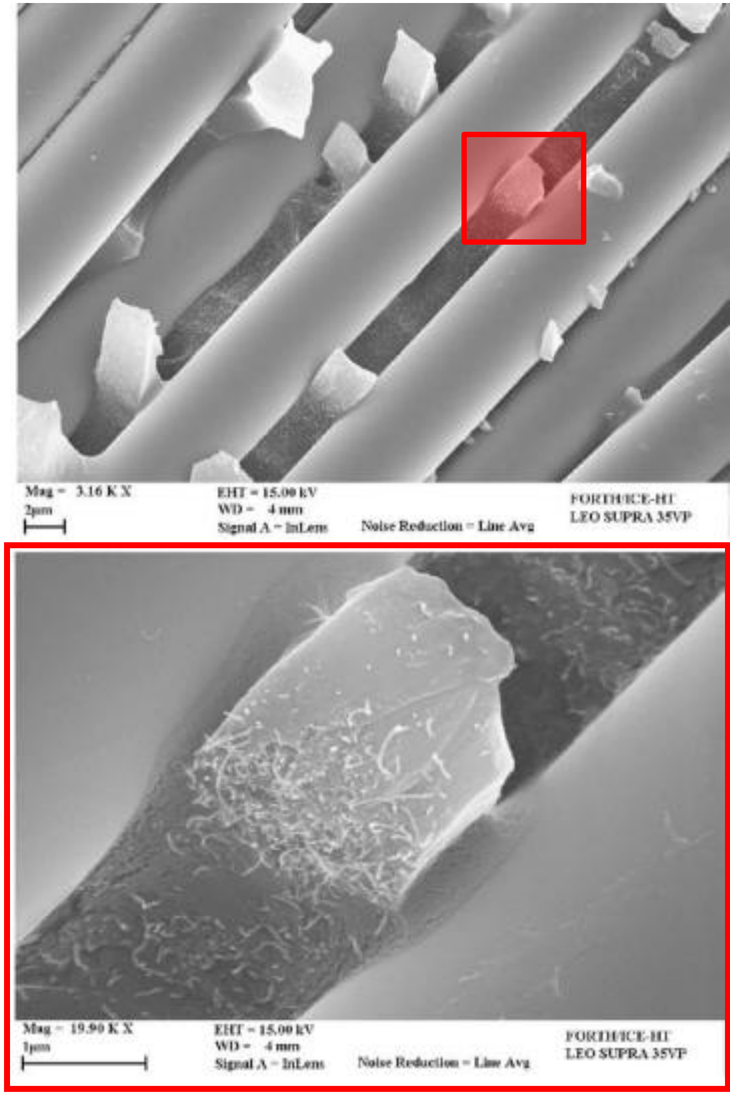


Wang et al. Nanotechnology 2008;19(7):075609

Scientific Origination

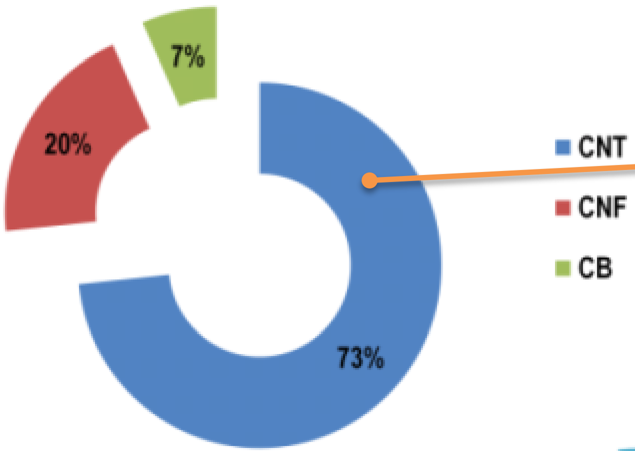
- Carbon Nanotubes
- Other Carbon-based species



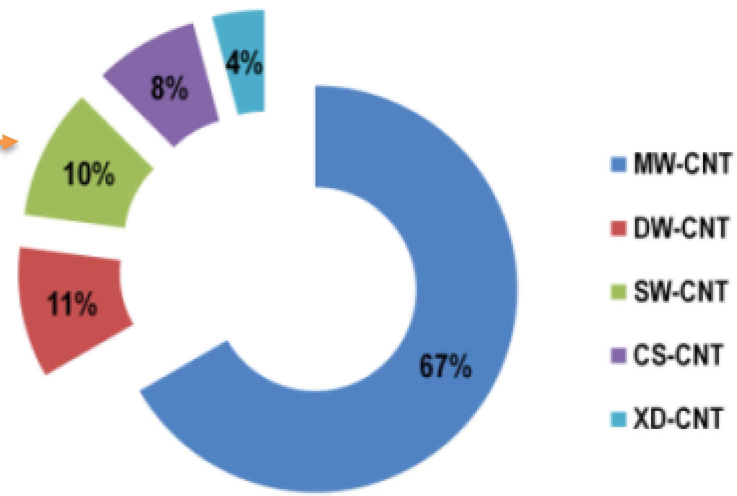


Former ESA Project *NAREMA survey*

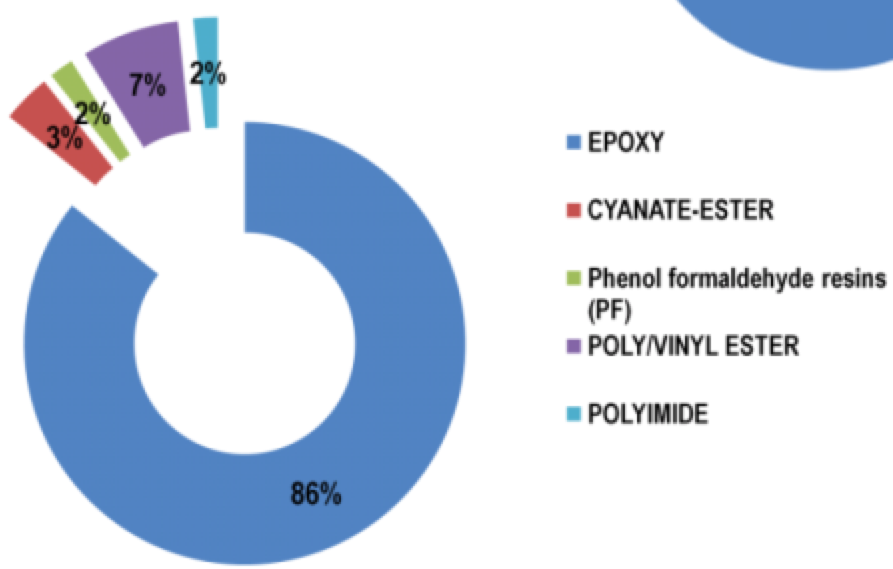
CNS Type

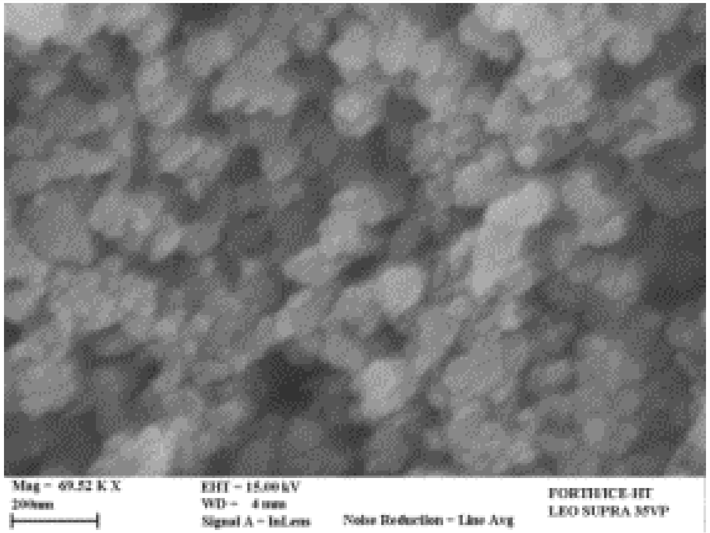


CNT Type



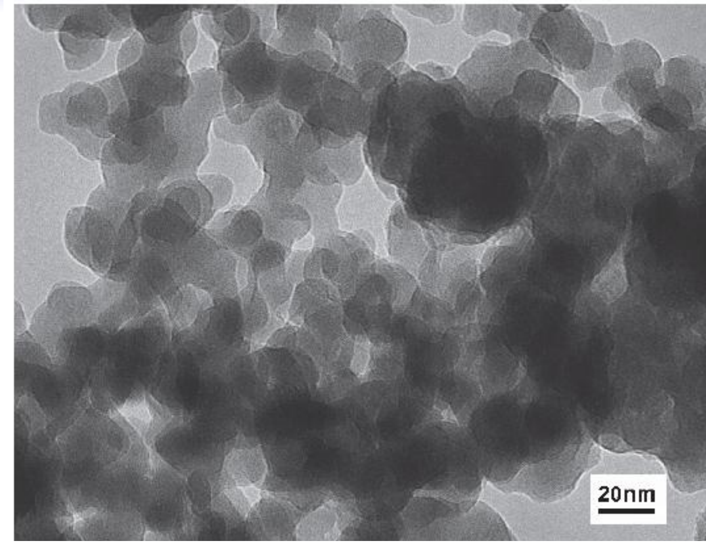
Matrix type

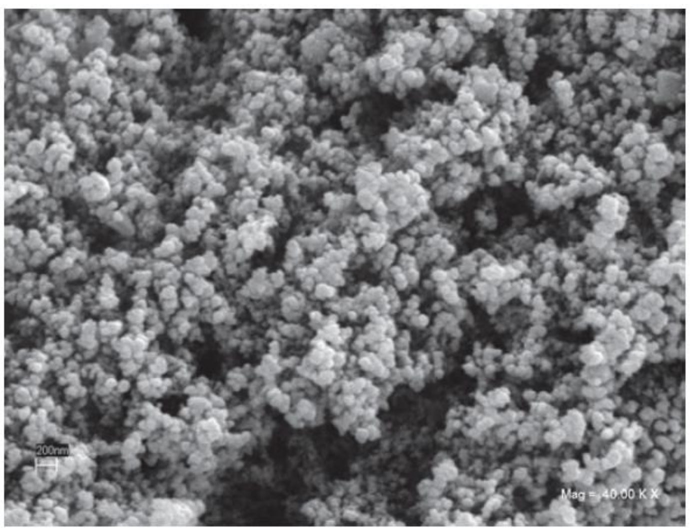




(a) Silicon Carbide

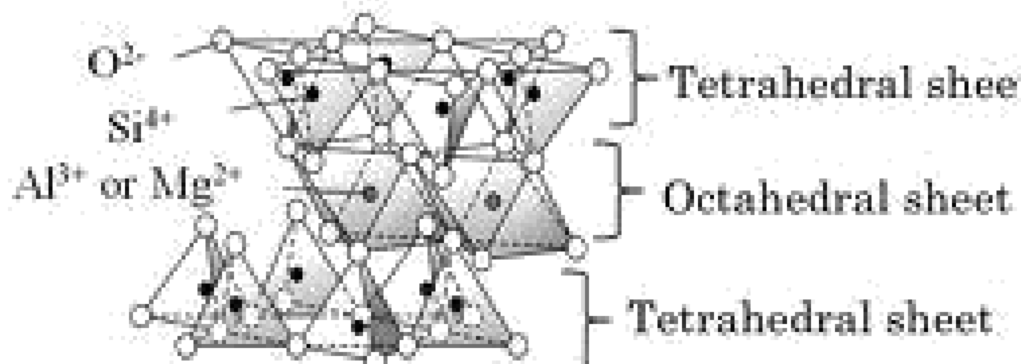
(b) Silicon Oxide

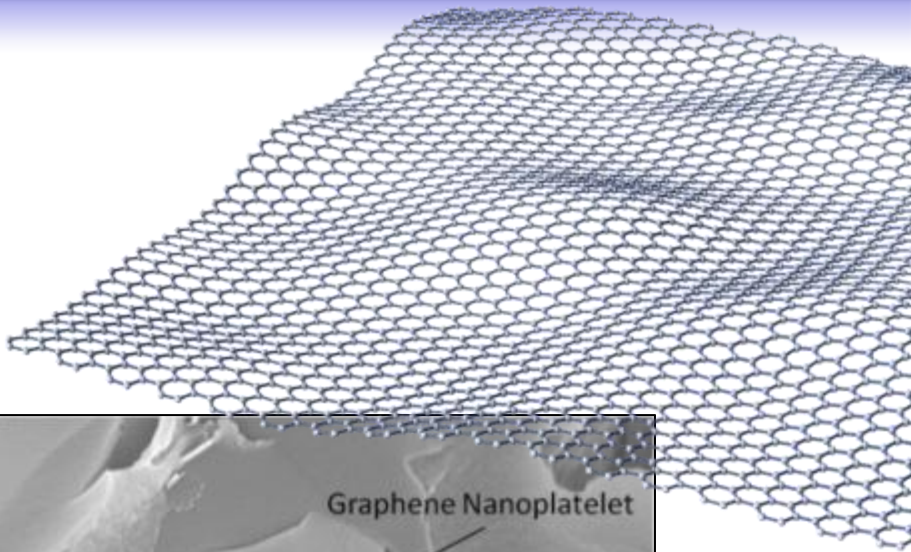




(c) Aluminum Nitride

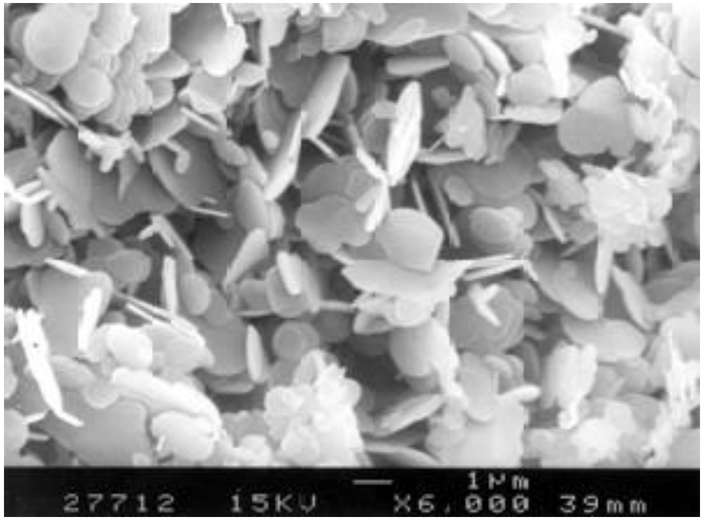
(d) Nano-clays

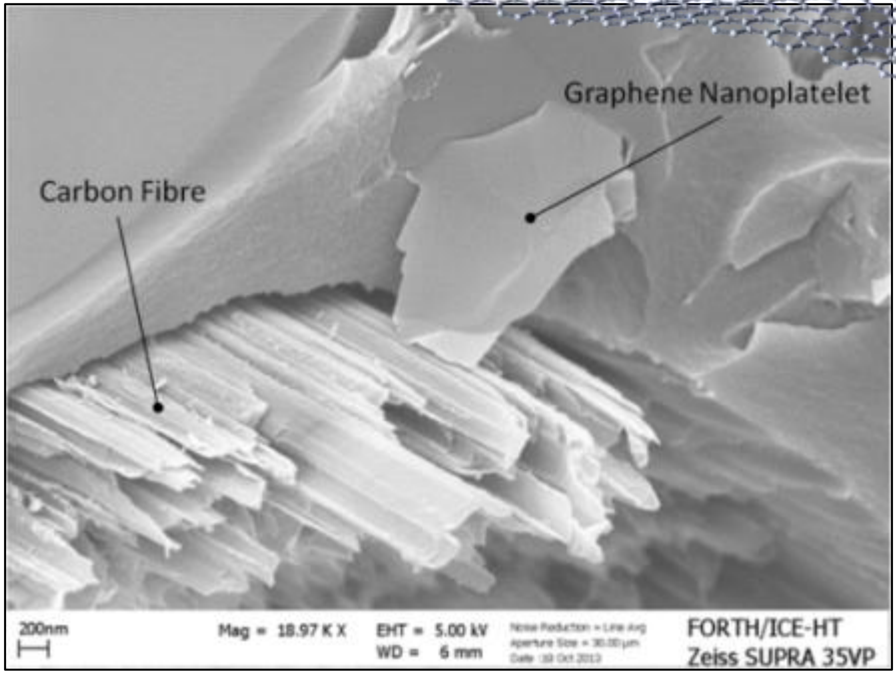




Graphene Nano-Platelets
(TR-)Graphene Oxide

Boron Nitride



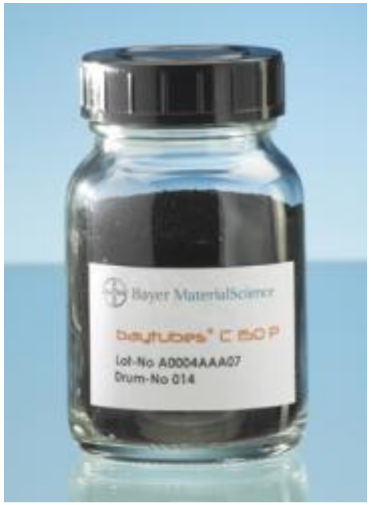


Courtesy: AML/UoP

Achieved performance

- Mechanical
  - Increased Fracture and Fatigue resistance
    - e.g. 100% Gic, 80% Giic
  - Improved damage tolerance
    - e.g. up to 40% CAI
- Electrical
  - Increase in trough thickness electrical conductivity
  - Up to 10 [S/m] using CNT
- Thermal
  - Improvement in through thickness conductivity
  - Up to 50% using hybrid nano-formulations

Indicative nano-enabled products for composites



Baytubes (Bayer Materialscience, D)

BuckyShield (Buckeye Composites, USA)

Raw MWCNT & Epocyl (Nanocyl, BE)

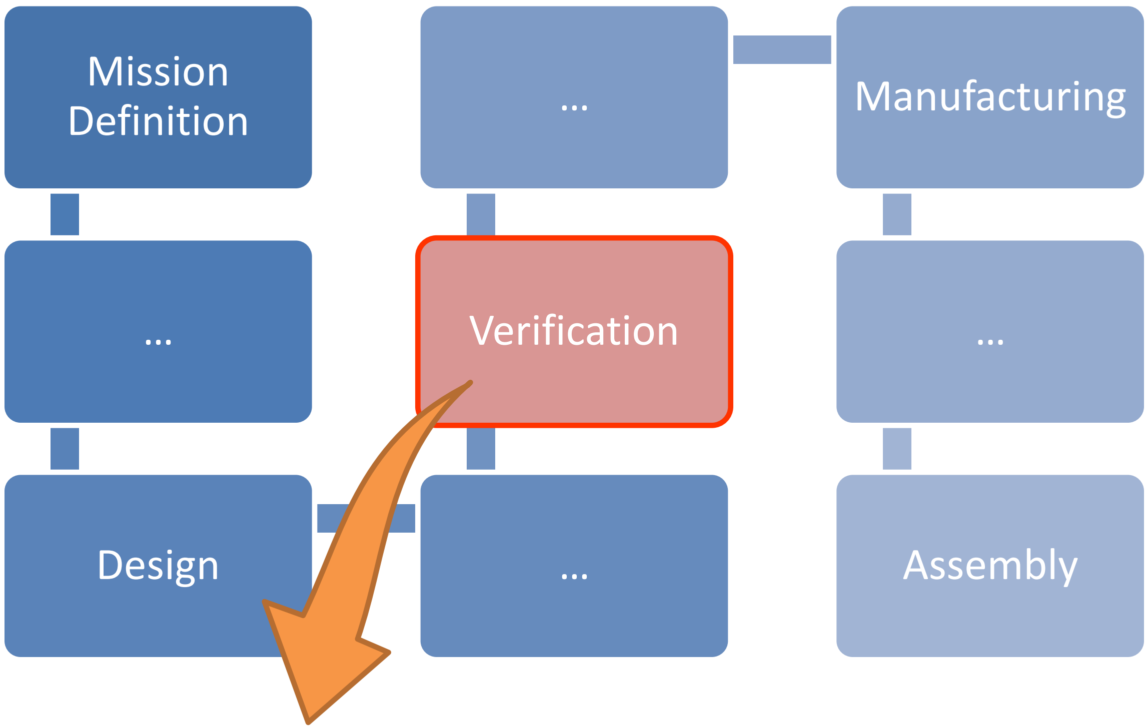
Implications of nanotechnologies

For industrial use

Challenge	Description
Incompatible production scale	*The proposed approaches work well at lab scale but investment on new production lines and processes are required to bring these technologies to industrial production.*
Compatibility with existing production methods	*Many of the proposed technologies require alternations in the supply chain and the production processes or at best special handling conditions*
Materials used are very specific	*It is very often the case that the results achieved are specific on the materials used and are not transferable to industrially used materials.*
Commercial availability and proprietary information	*Commercial availability of the materials is limited or restricted for certain products (e.g. resins, fibres).*
Quality assurance in industry	*Quality assurance measures are not yet defined for such nano-enabling processes and in some cases may violate already established standards.*

Technology adoption drivers: Performance
Compatibility

- The road to the launch

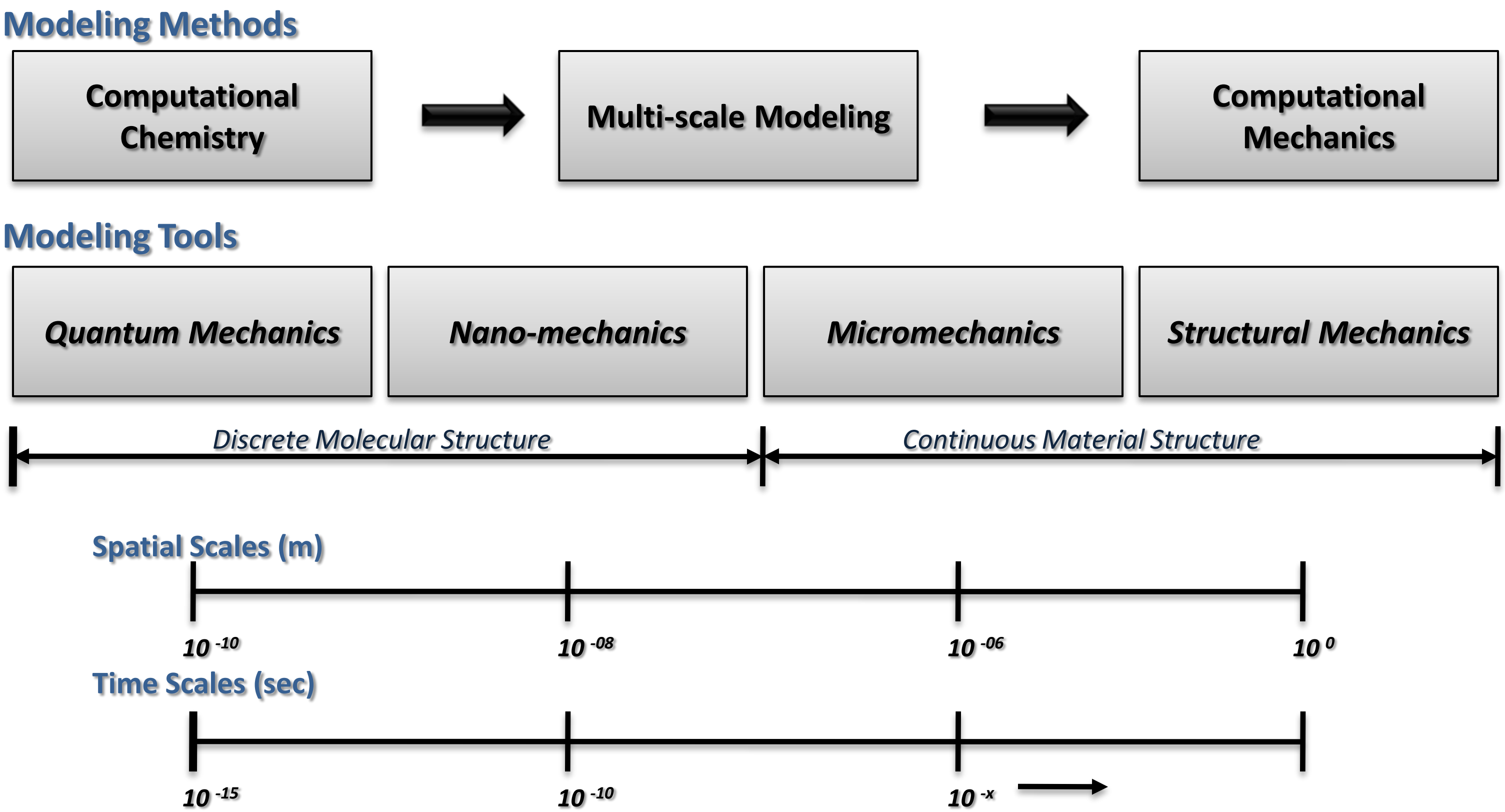


Modeling

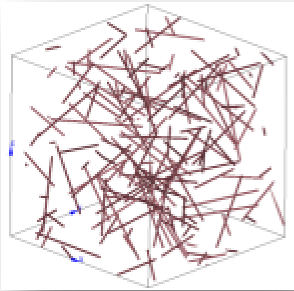
“If you cannot model it, you can’t fly it”

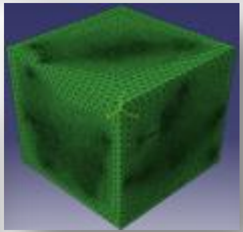
- Based on physical and chemical principles, predict material properties
- Understand trends and capabilities of materials
- To predict the performance of the materials under service conditions
- To design materials according to application needs

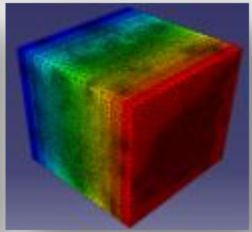
Nano-modeling capabilities *Available approaches*

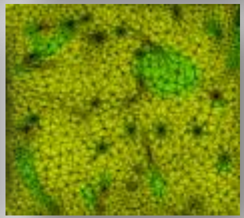


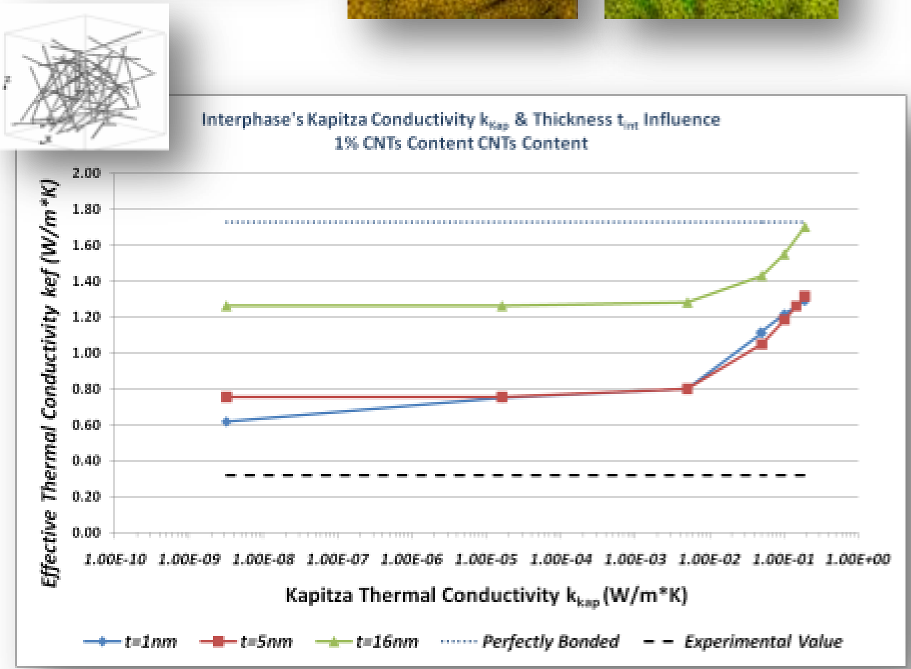
Electrical and Thermal properties

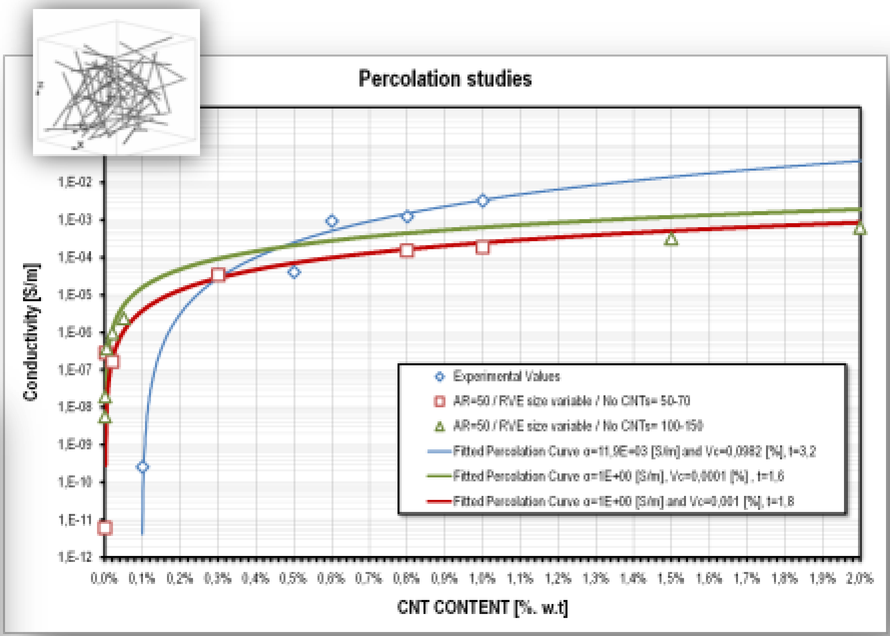






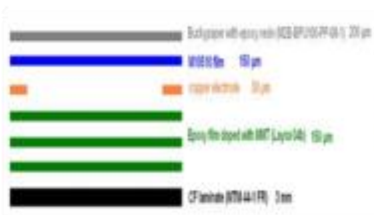






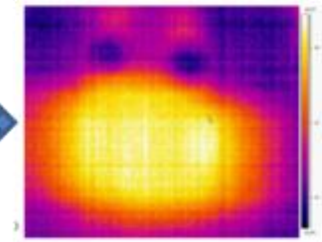
Nano-modeling capabilities *Multi-physics problems*

Experiment

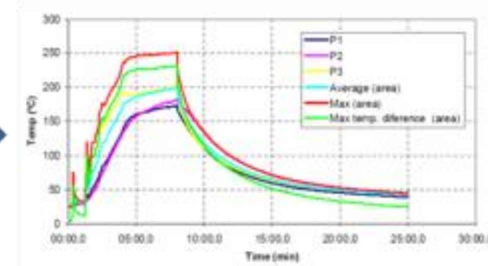


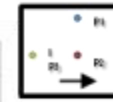
Experimental Layer Set Up

Application of Electrical Power Pe At RT



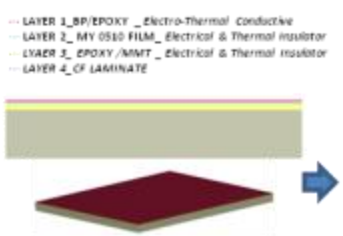
Heat of Top Specimen Surface due to Joule Phenomenon





1st Modelling Approach

FEA Model



Computational Layer Set Up

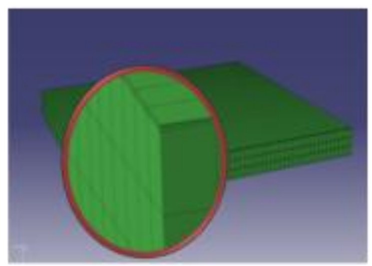
Material Model Variables

ρ, σ, k, c_p, η, hair

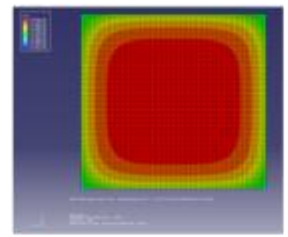
Where:

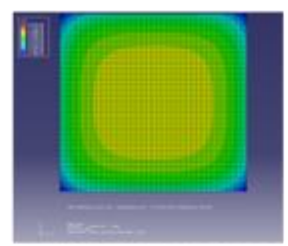
$\sigma \rightarrow$ derived by the NrPM_RVE developed for the Electrical Analysis

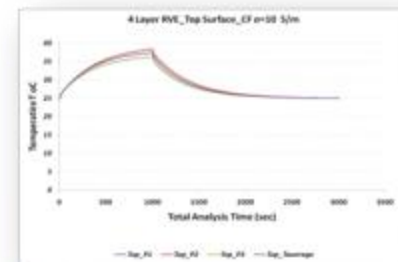
k, $c_p \rightarrow$ derived by the NrPM_RVE developed for the Thermal Analysis

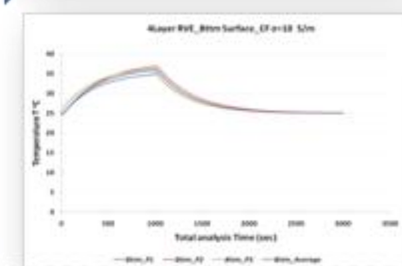


Application of Electrical Power Pe At RT



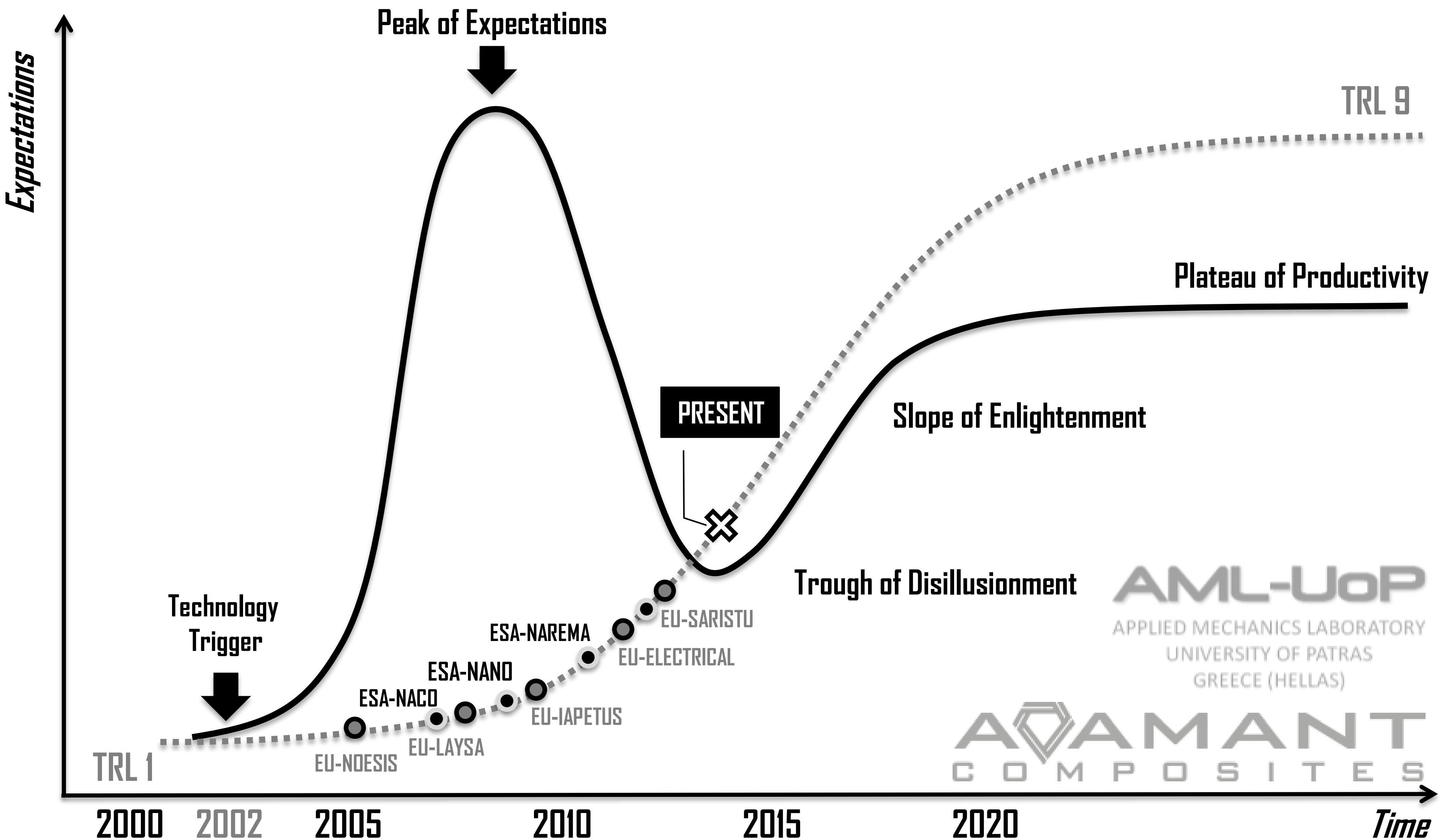






Estimation of TRL

NANO-ENABLED COMPOSITES HYPE



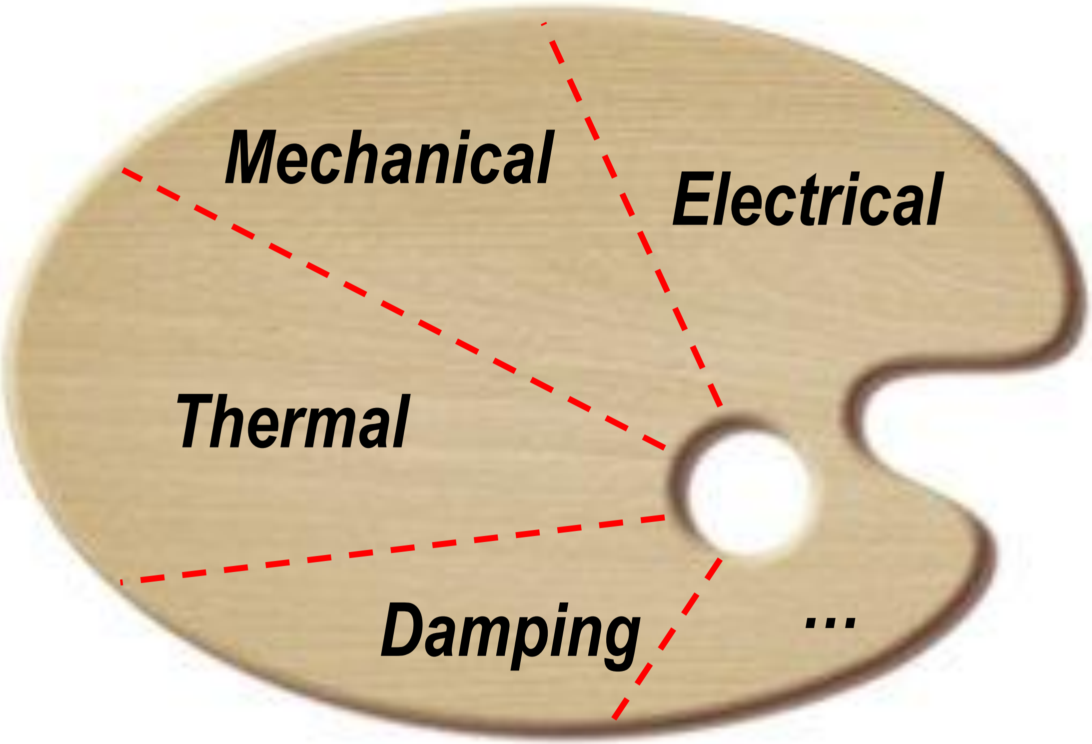
Perspectives

- Targets to be achieved still remain:
  - Enable passive multifunctional utilization
    - Thermal conductivity
    - Electrical conductivity
    - EM compatibility
  - Reduce mass and improve strength

- "Made to Measure" materials

Made-To-Measure Philosophy

Nano-materials palette *For nano-enabled composites*



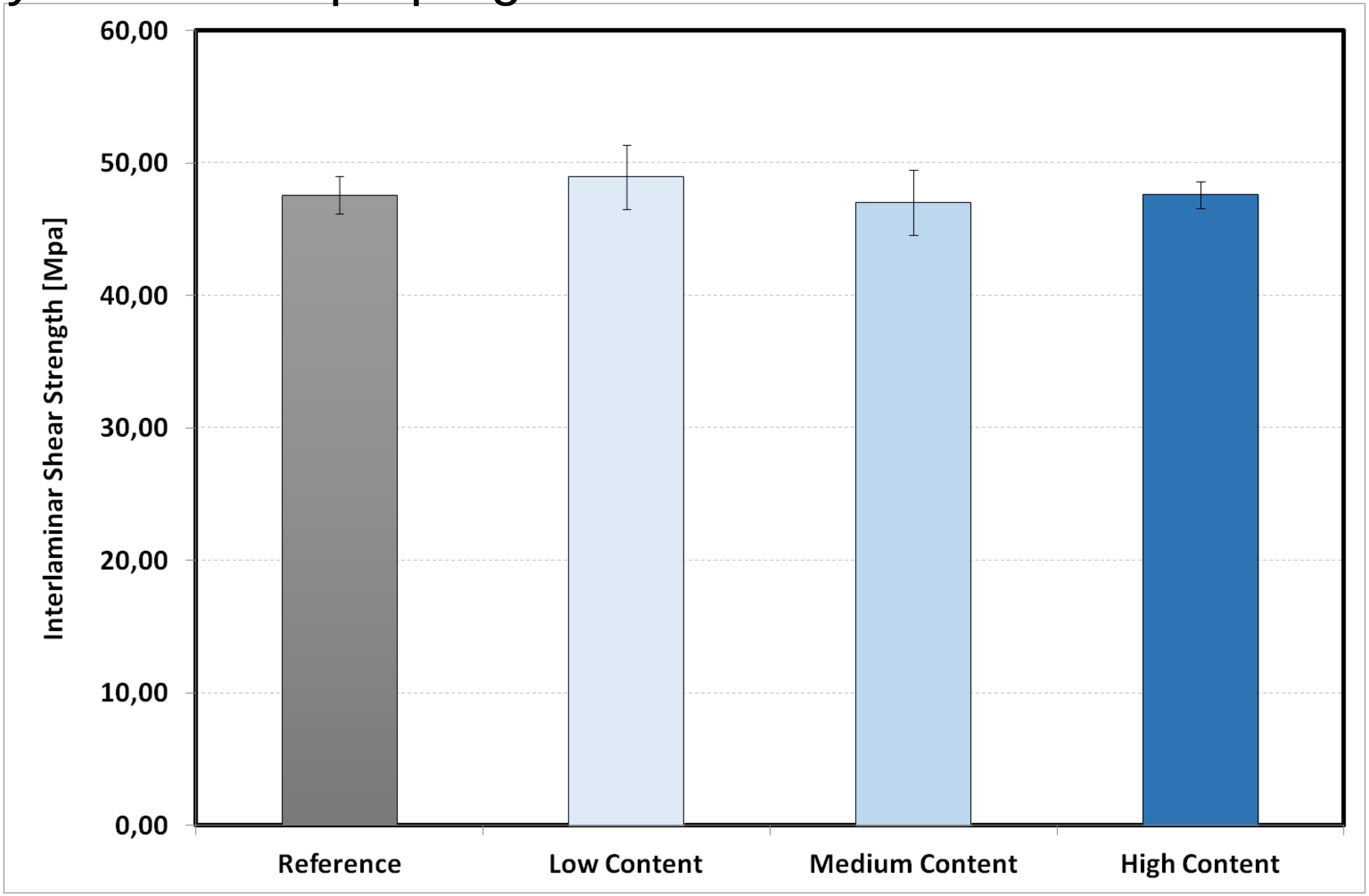
Nano-Enabling Technology *For prepregs*

- Applicable to already commercial prepregs

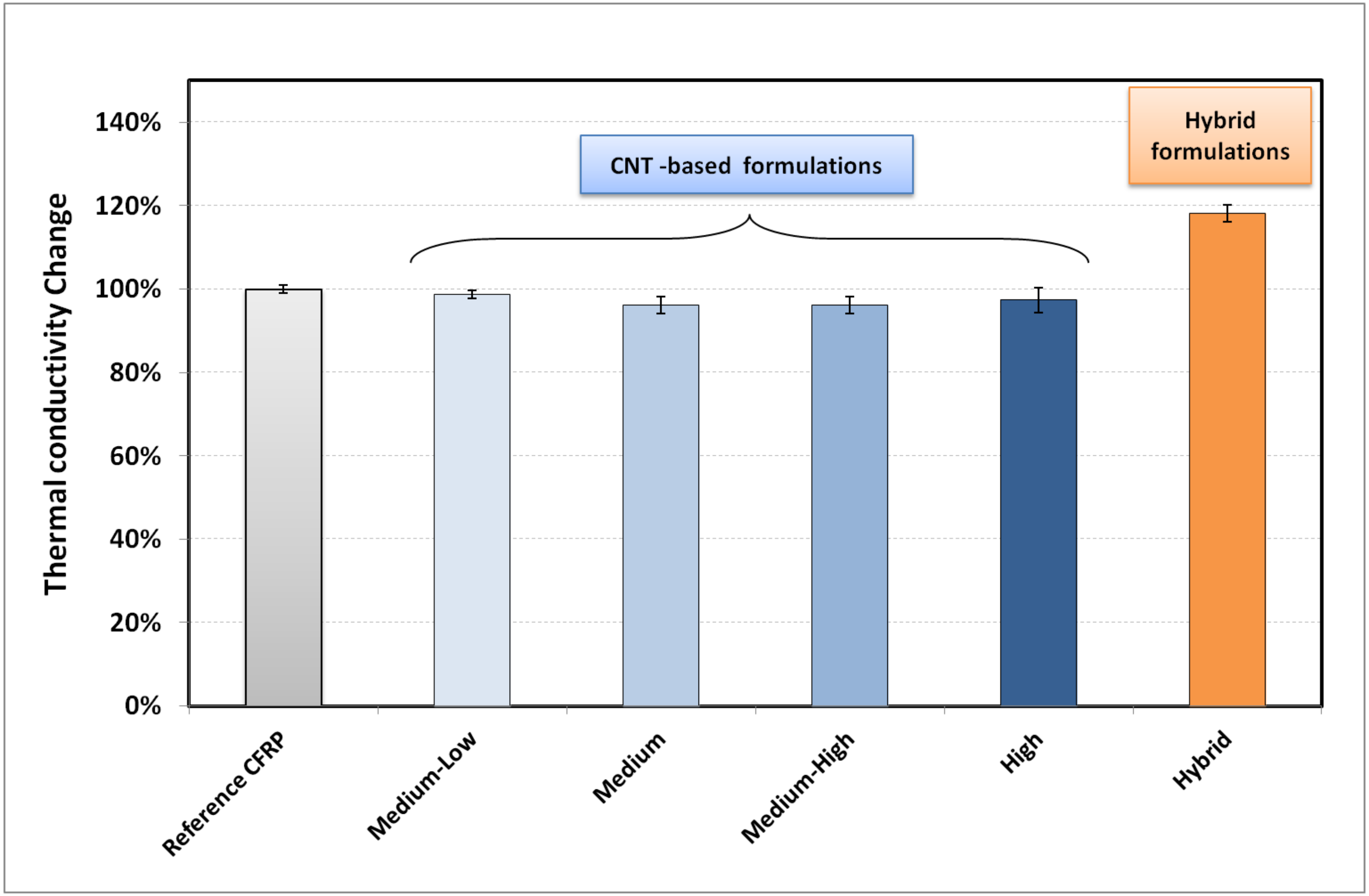
- Develop a suitable nano-formulation
- Introduce the nano-formulation into the material
- Calibration trials for composite processing
- Evaluation of the produced composite's performance

- Given the requirements (input) we develop the nano-formulation and run the evaluation process

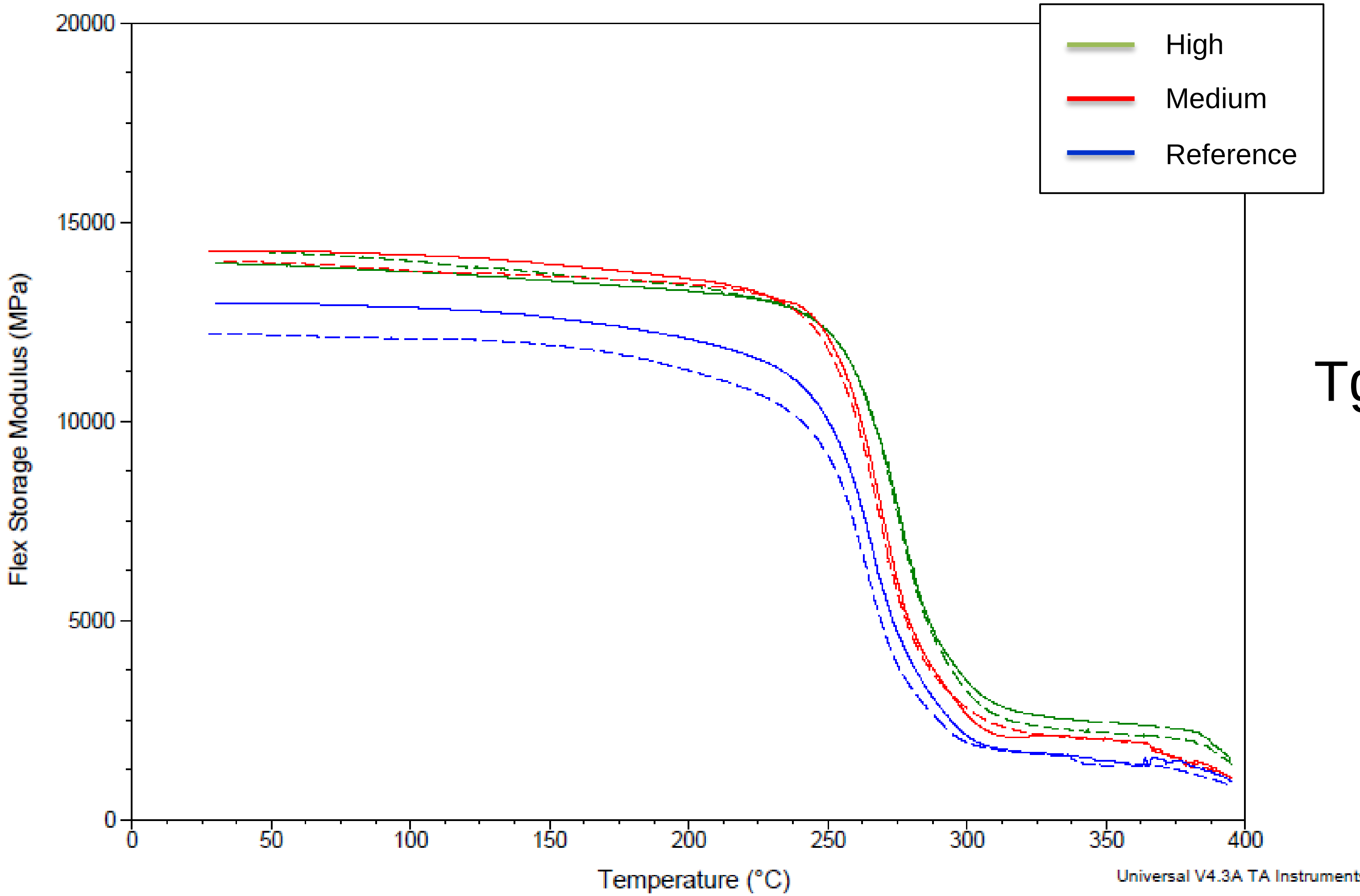
Cyanate ester prepreg with CNT formulations



Cyanate ester prepreg with CNT and Hybrid formulations



Cyanate ester prepreg with CNT formulations



Tg > 220^{o}C

Acknowledgements

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NANOTECHNOLOGIES FOR COMPOSITE STRUCTURES

From Nanocomposites To Multifunctional Nano-Enabled Fibre Reinforced Composites For Spacecrafts

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