# DEVELOPMENT AND STUDY OF LAMINATED COMPOSITE MATERIAL INTEGRATING CARBON NANOTUBES FOR LAUNCHER CRYOGENIC TANK APPLICATION

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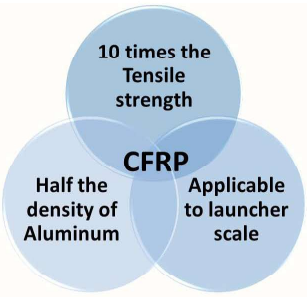
## Context of this study:

**Cryogenic fuel tanks** count for **more than 80%** of the **dry weight** of a launcher. **A more performant alternative** to their current design would be **carbon fiber reinforced polymer (CFRP)**.

**From density 2,7 to 1,5, replacing aluminum with CFRP is an economic necessity.**




**It is necessary for these CFRP composites to:**

**Prevent microcracking** at **cryogenic temperatures** (-200°C) → **Resist** the **oxidizing** effects of the **Liquid Oxygen** environment → **Maintained Overall structural integrity & Absence of leaks**

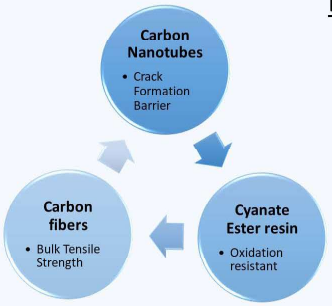
**As it stands, CF/Epoxy composites aren't resilient enough for cryofuel tanks.**

**A new optimized composite material is needed for the application**

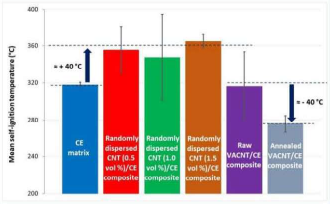
## This work:

**The stratified association of Carbon nanotubes (CNT), Carbon fiber (CF), and Cyanate ester resin (CE) holds a high potential for cryogenic applications.**

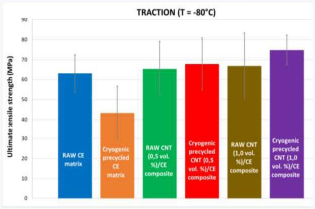
This study aims to **determine the best of three** different **processing ways** to **integrate CNT** into a stratified **carbon fiber/cyanate ester composite.**




## Previous works: CNT/Cyanate ester composites




Mean self-ignition temperature of CE/CNT composites under oxygen atmosphere*




Tensile strength of CNT/CE composites before and after cryogenic cycling

**CNT/CE synergize in regards to oxidation and cryogenic cracks resistance**

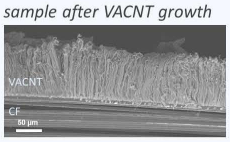
*Bouillonnec, Champonnois et al, EUCASS Proceedings (2022)*

## Direct growth of vertically aligned CNT forests on carbon fiber textile

**Synthesis** (LEDNA)
- On a 30cm $SiO_x$ covered carbon fiber cloth, in a 800°C furnace.
- Of up to 300 µm thick VACNT carpets

*30cm*5cm carbon fiber sample after VACNT growth*

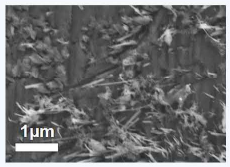
**Stacking, infusion, and polymerization**
- To make samples fit for mechanical testing. (CMP)




*SEM of VACNT on Carbon fibers*

*Stratified composite rough sample*

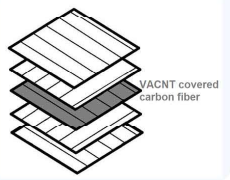
**Mechanical testing** (I2M)
- Cyclic traction trials
- Observing crack formation via optical microscopy
- At cryogenic temperatures




*Zoomed in SEM of VACNT in a CF/CE stratified composite*

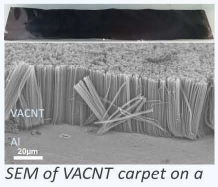
**+ Covalent binding** between **CF** and **CNT**
**+ Growth of VACNT through CF textile**
**+ Control over CNT length**
- **CF** slightly **damaged** by the **high temperature** of the **VACNT synthesis**

**Final sample architecture**



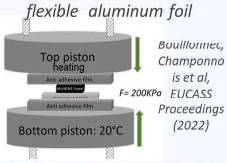

## Hot pressing transfer of VACNT on preimpregnated carbon fiber textile

**Synthesis** (LEDNA)
- On a 25 cm, flexible aluminium foil in a 615°C furnace.
- Of up to 100 µm thick VACNT carpets by CCVD




*SEM of VACNT carpet on a flexible aluminum foil*

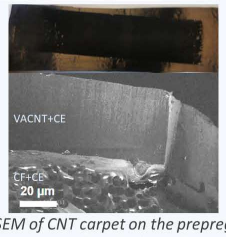
**Hot pressing transfer** (LEDNA)
- On a 25*5cm VACNT carpet
- On a prepreg composite
- Hot CE Resin permeates the VACNT carpet




*Bouillonnec, Champonnois et al, EUCASS Proceedings (2022)*

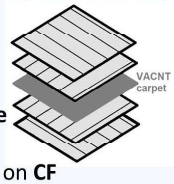
**Stacking & polymerisation**
- To obtain a sample fit for mechanical testing (CMP)

**Mechanical testing** (I2M)
- Cyclic traction trials
- Observing crack formation via optical microscopy
- At cryogenic temperatures




*SEM of CNT carpet on the prepreg composite after Transfer*

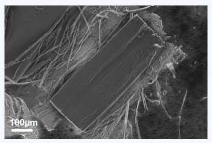
**Final sample architecture**




**+ Undamaged carbon fibers**
**+ Maintained CNT alignment**
**+ Control over CNT length**
- Presence of **CNTs only at the interlayer**
- **No covalent binding** of **CNT** on **CF**

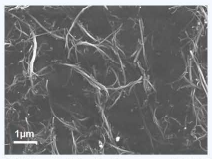
## Dispersion of CNT within the cyanate ester matrix

**Synthesis** (LEDNA)
- In a 800°C quartz reactor
- Of 400 to 600 µm thick VACNT carpets by CCVD




*SEM of VACNT out of synthesis.*

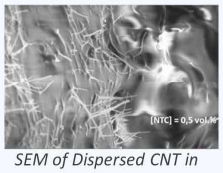
**Dispersion** (LEDNA)
- In water with 1%m Brij® S20
- Via a sonic probe




*SEM of dried dispersed CNT after sonication.*

**Mixing, stacking & infusion**
- Mixing hot cyanate ester resin with CNT dispersion under vacuum to dehydrate (CMP)

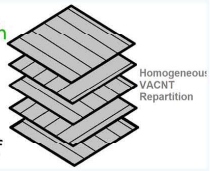
**Mechanical testing** (I2M)
- Cyclic traction trials
- Observing crack formation via optical microscopy
- At cryogenic temperatures




*SEM of Dispersed CNT in CE resin.*

**+ Undamaged carbon fibers**
**+ Homogeneous** presence of **CNT** through the **matrix**
- **CNT length** reduced to roughly **1µm**
- **No covalent binding** of **CNT** on CF

**Final sample architecture**




## Conclusion:

- Several **sample sets of composite** architectures integrating **carbon nanotubes, carbon fibers and cyanate ester** have been produced.
- **Mechanical characterizations** will reveal the **influence of CNT length and concentration on mechanical properties.**
- **The mechanical behavior** of samples for each investigated processing ways will be **characterized at room temperature** and under a **cryogenic environment**
- Investigation of the **influence of CNTs** on **crack propagation** in CF composites at **room temperature and in Liquid $N_2$.**