MINISTÉRIO DA CIÊNCIA E TECNOLOGIA
INSTITUTO NACIONAL DE PESQUISAS ESPACIAIS

Effect of the CVD parameters on the fiber tensile strength of carbon fibers using single-fiber tensile test after carbon nanotubes growth

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SUMMARY

- **MOTIVATION**

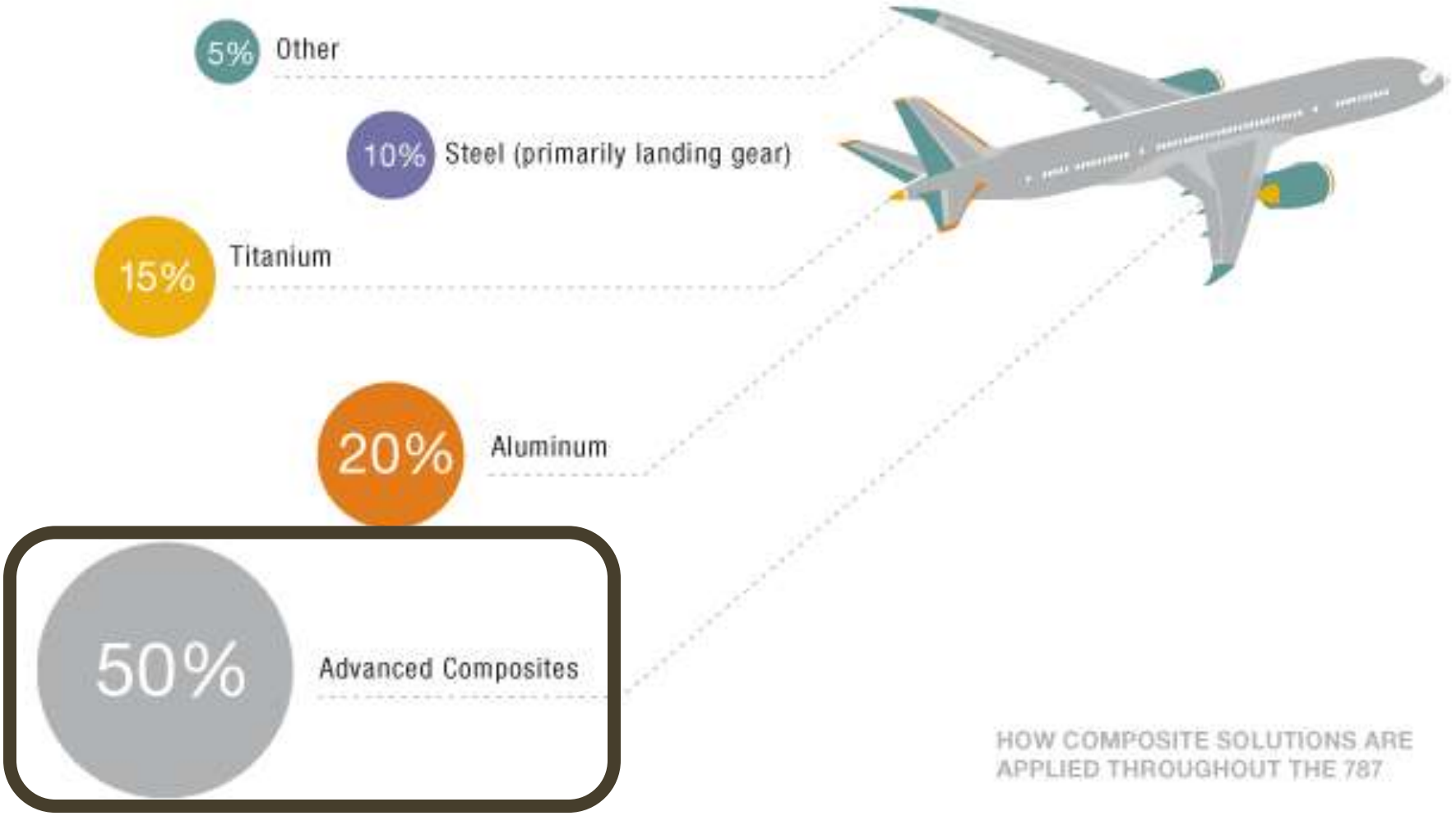
- **INTRODUCTION**
  - Carbon Nanotubes Growth models
  - Fuzzy Fiber
  - Nanostitching

- **CARBON NANOTUBES PRODUCTION**

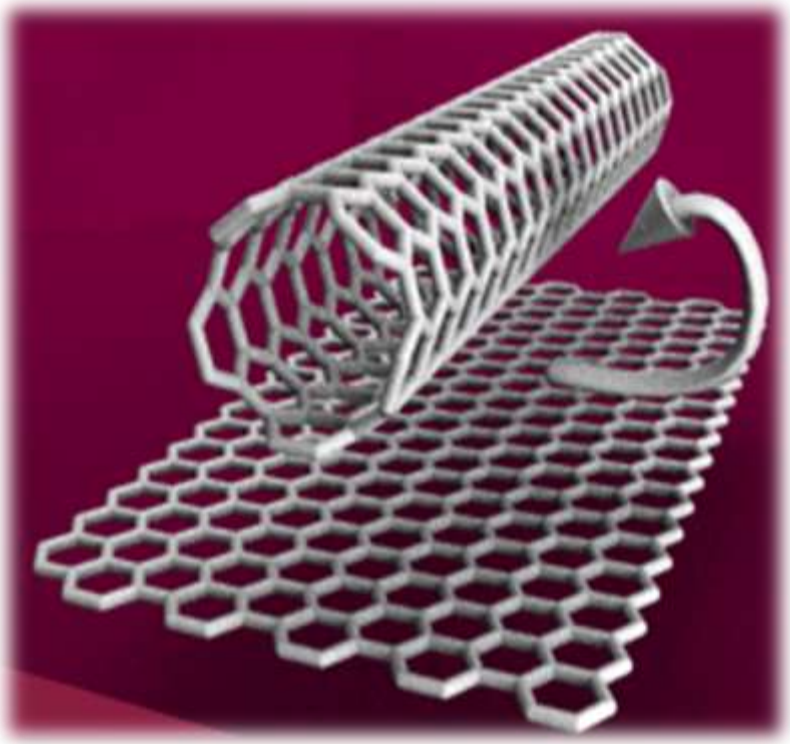
- **SINGLE FIBER TENSILE STRENGTH TEST**

- **RESULTS**
  - SEM – FEG images
  - Weibull distribution

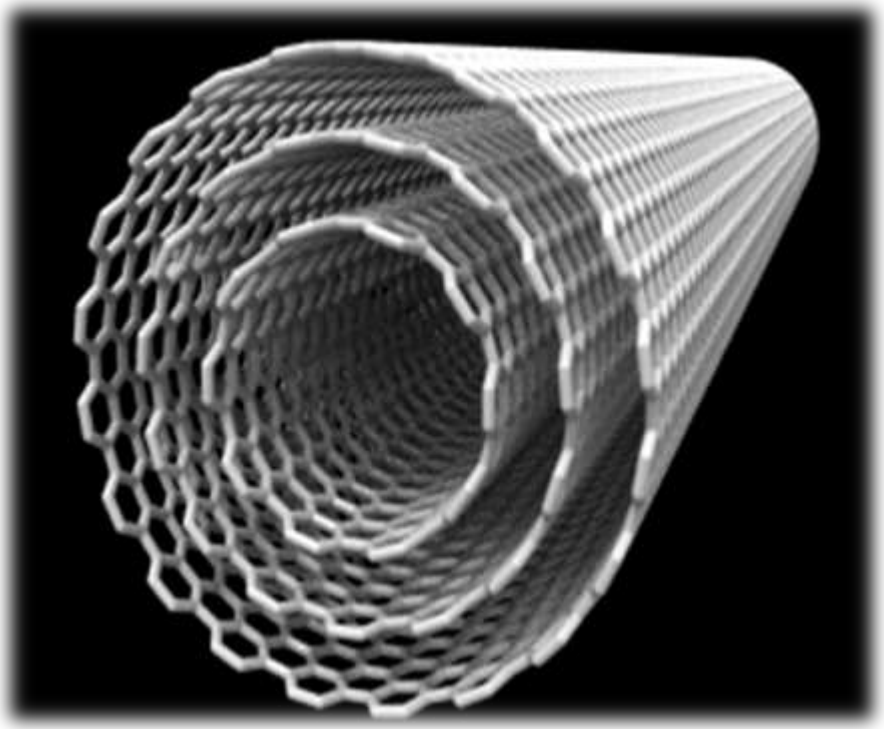
Motivation


5% Other
10% Steel (primarily landing gear)
15% Titanium
20% Aluminum
50% Advanced Composites
HOW COMPOSITE SOLUTIONS ARE
APPLIED THROUGHOUT THE 787

Introduction



Single Wall Carbon Nanotube (*SWCNT*)

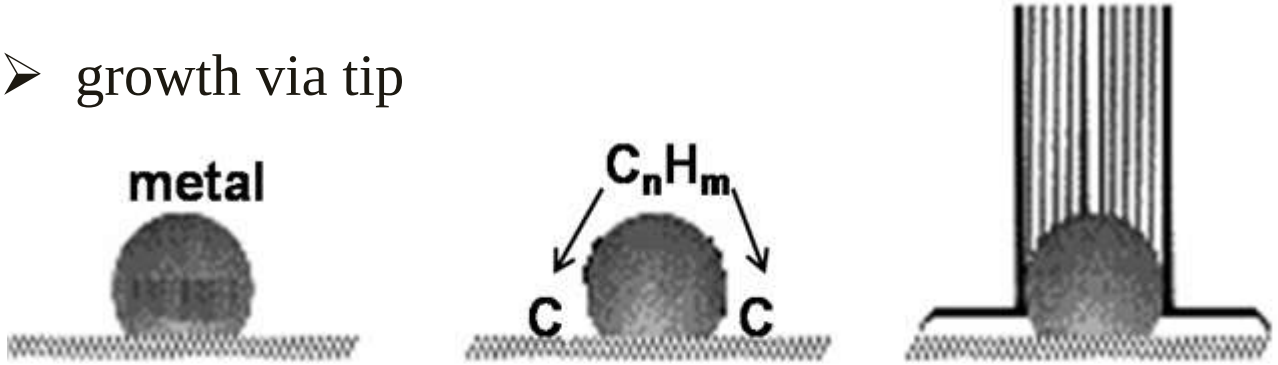


Multi Wall Carbon Nanotube (*MWCNT*)

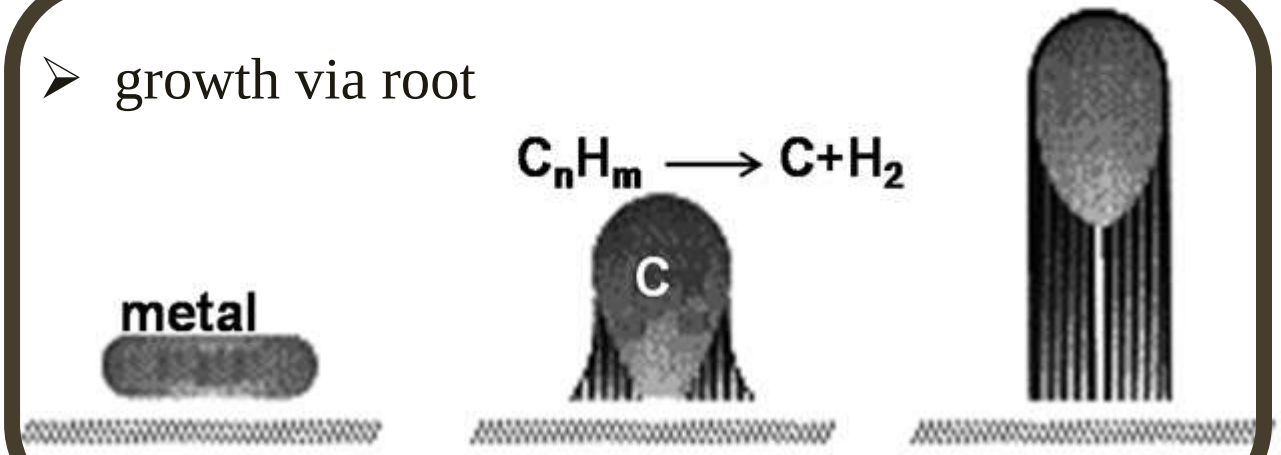
Carbon Nanotubes Growth Models

- **Depends on the catalytic nanoparticle adhesion**

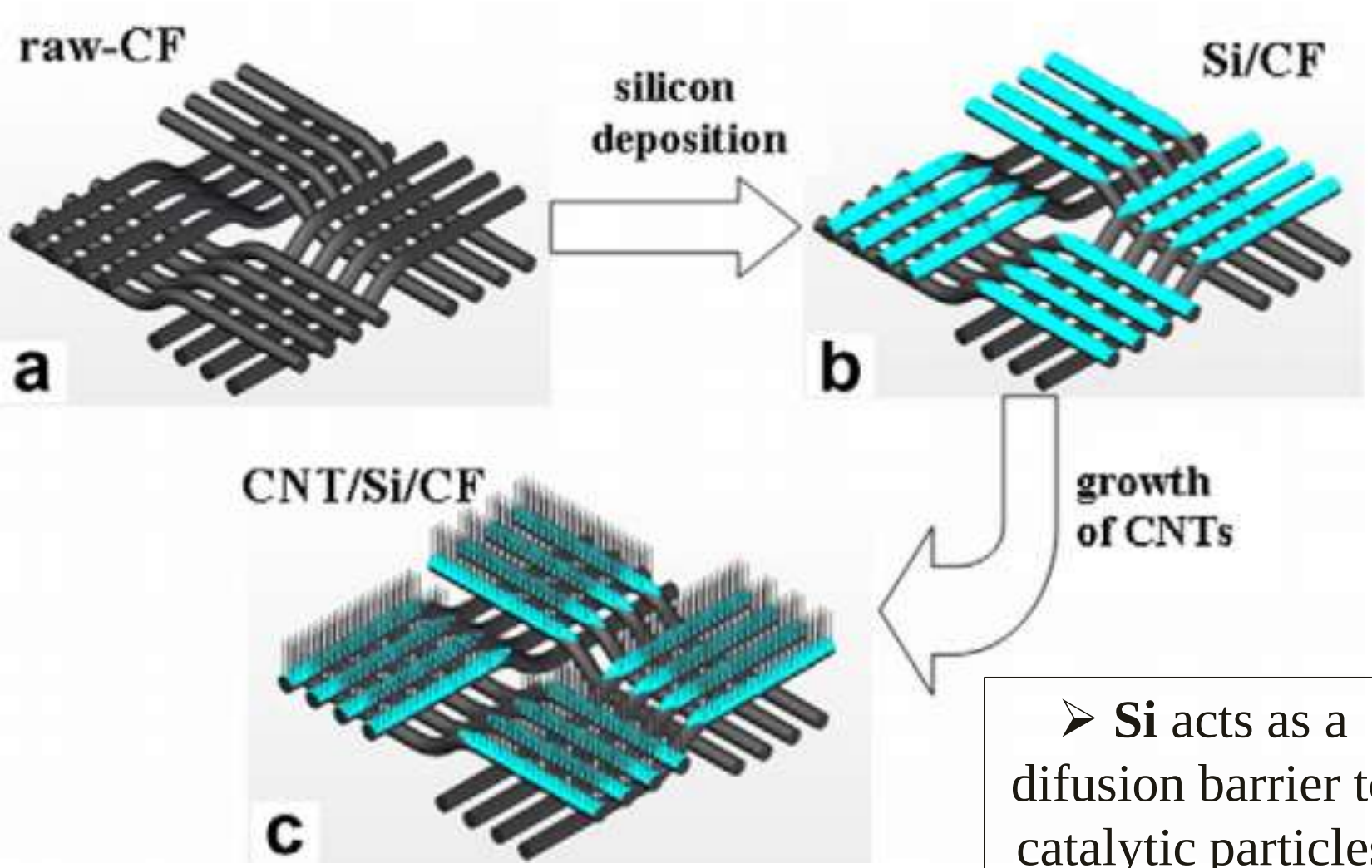
➢ growth via tip



➢ growth via root



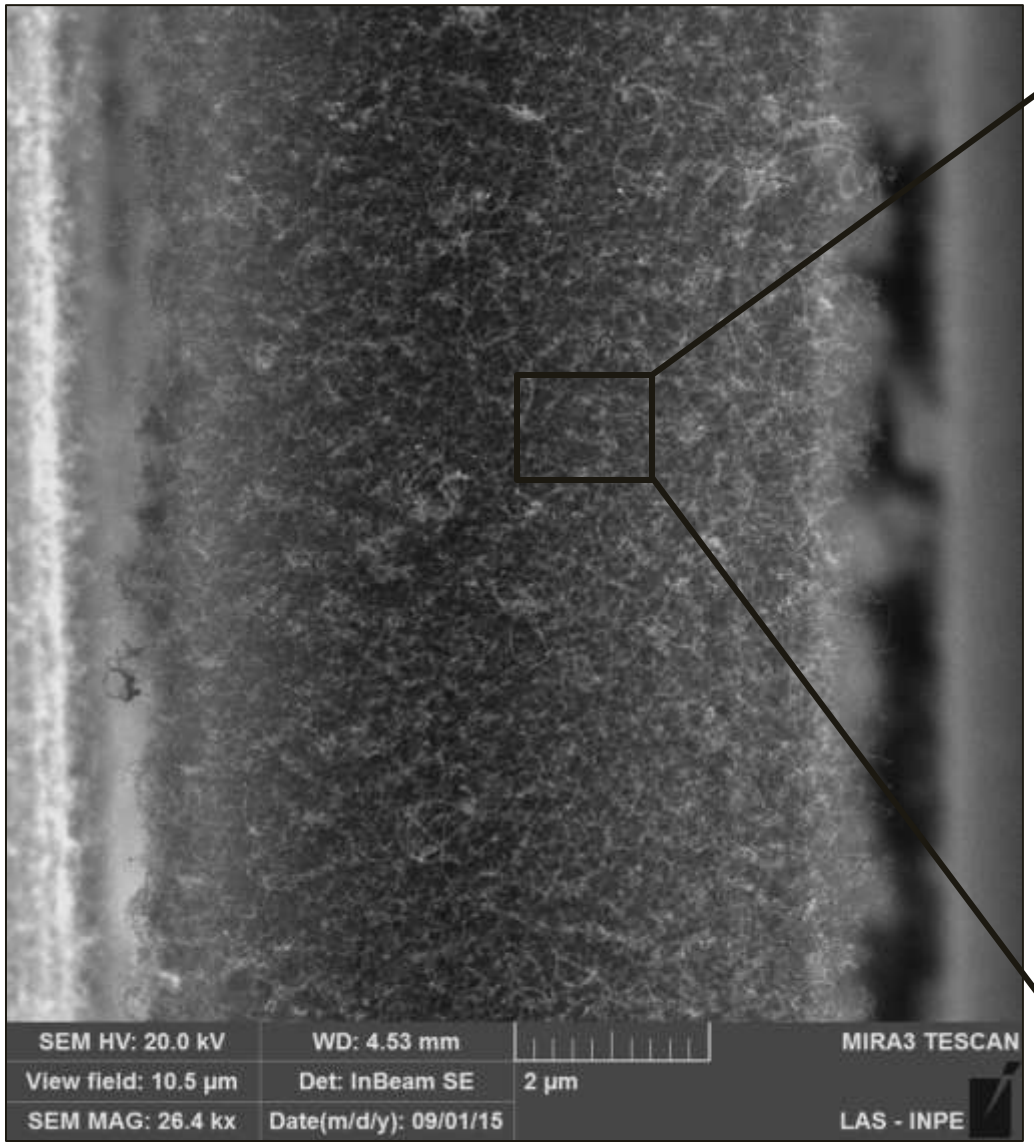
Steps needed to CNTs perfect growth on CF surface

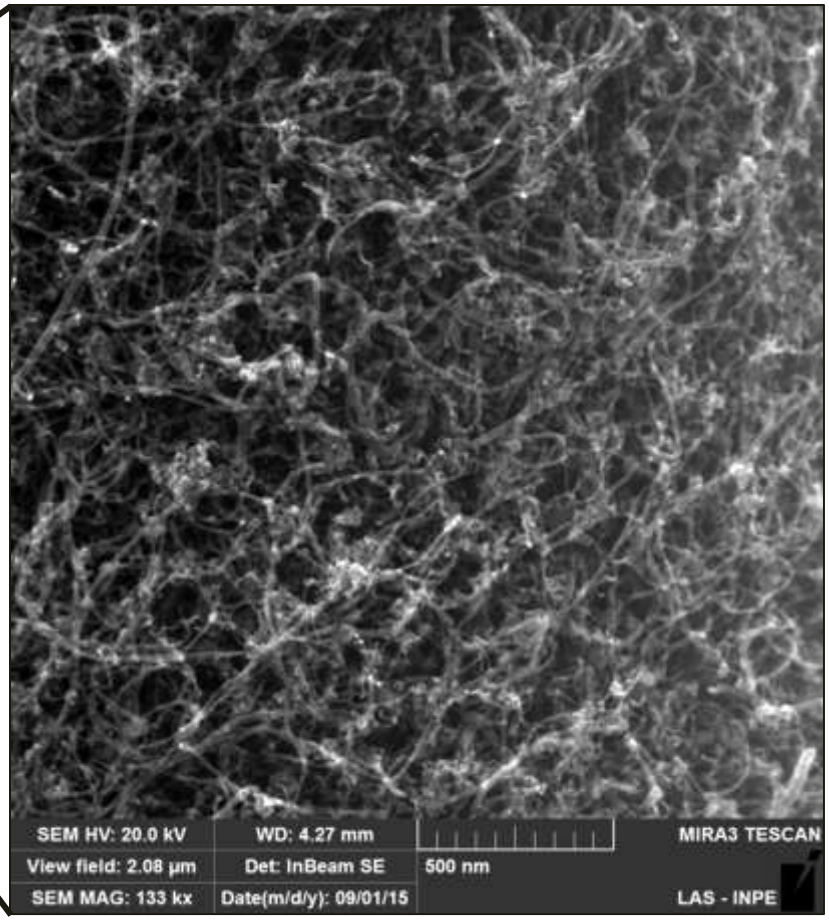


➢ **Si** acts as a difusion barrier to catalytic particles

* Reference [1]

✓ CNTs grown on CF surface after Si deposition

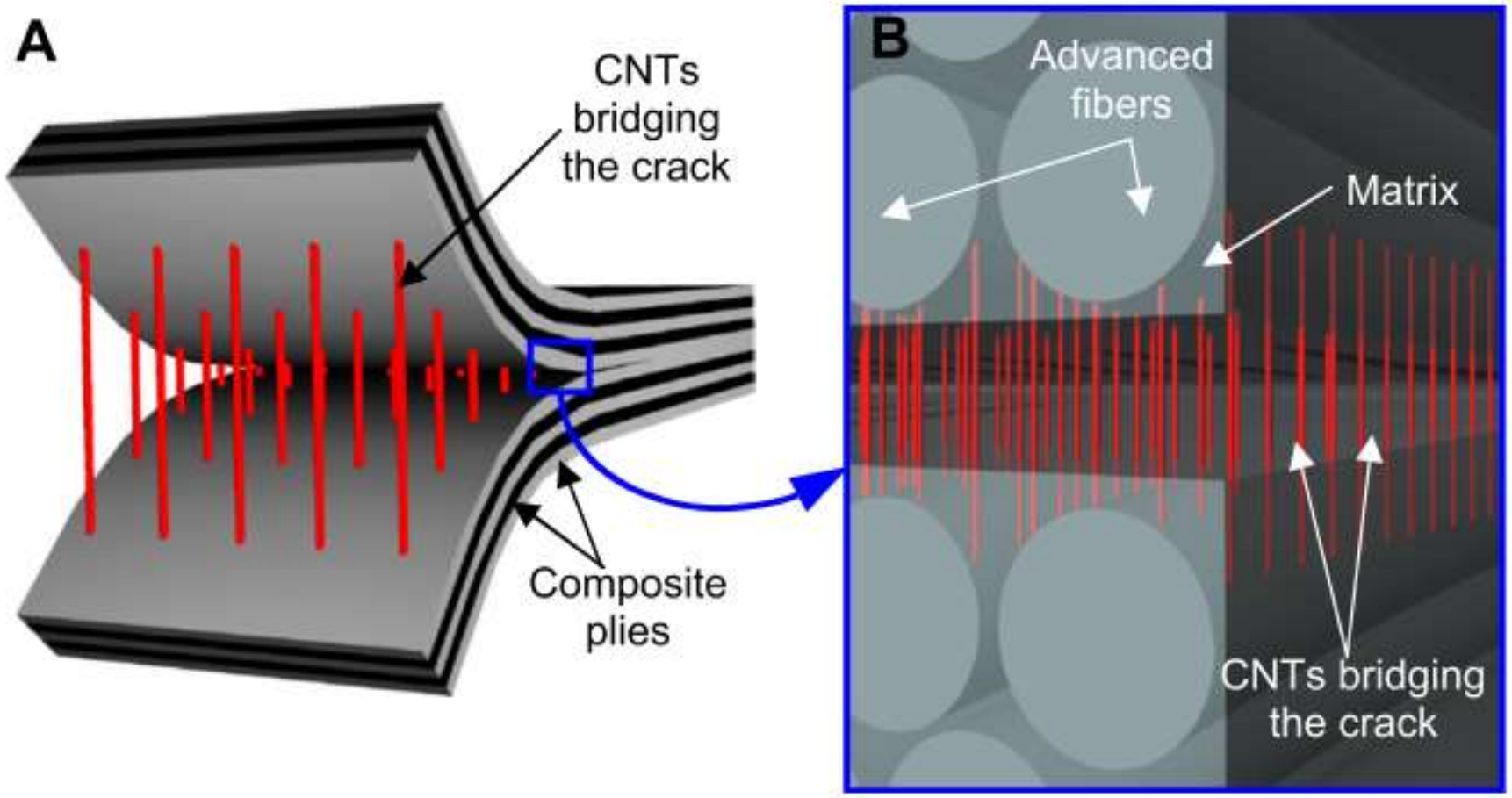




➢ Homogeneous CNTs growth

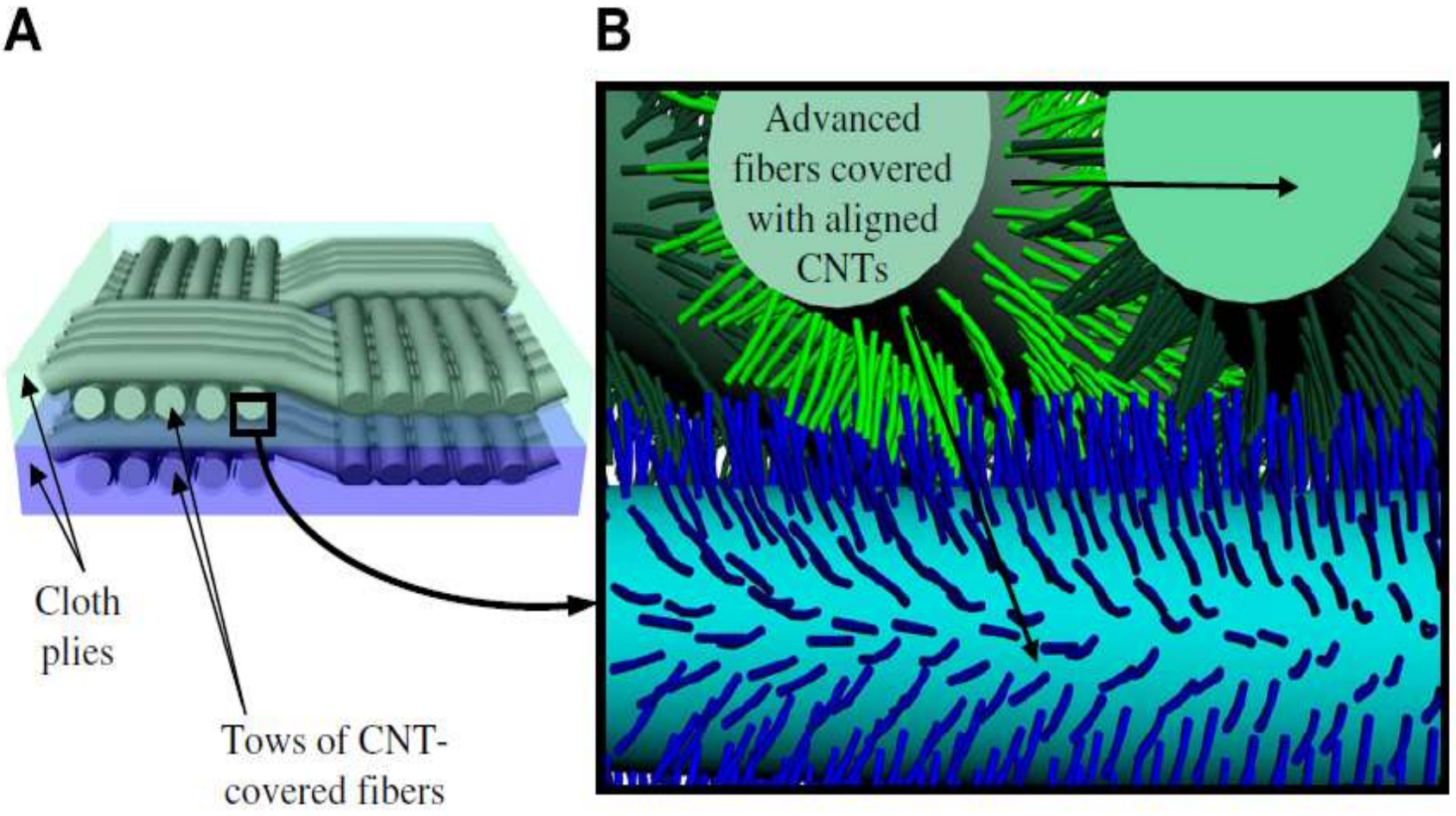
Objective

- **Grown CNTs on CF surface to reinforce the interlaminar shear strength**



* Reference [2]

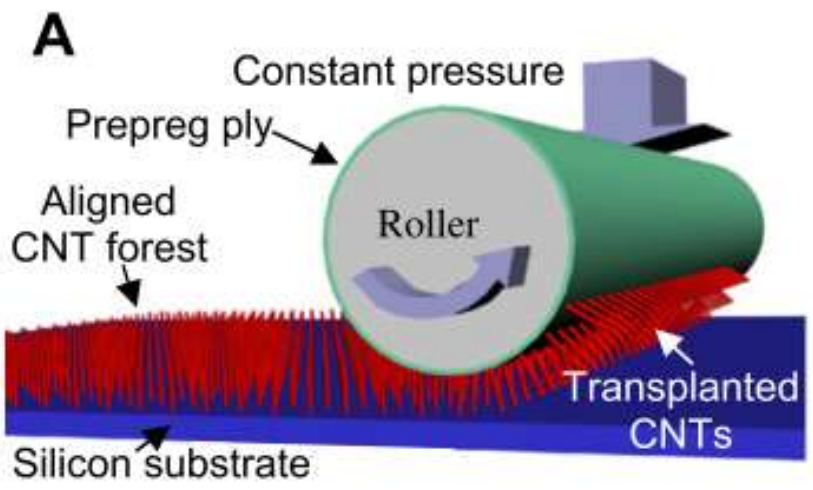
- **Fuzzy Fiber** → CNTs are grown radially on CF surface

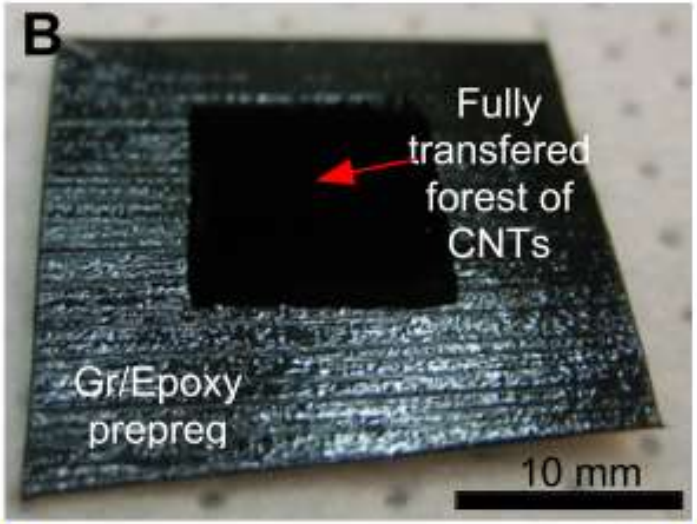


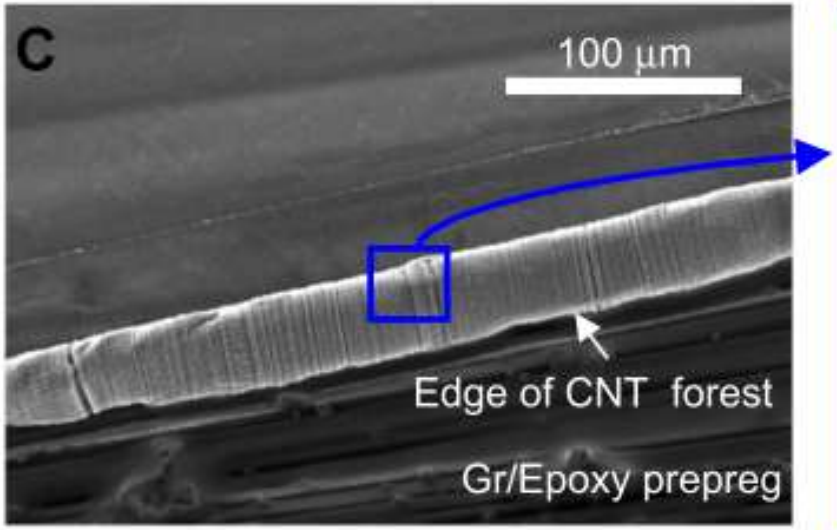
* Reference [3]

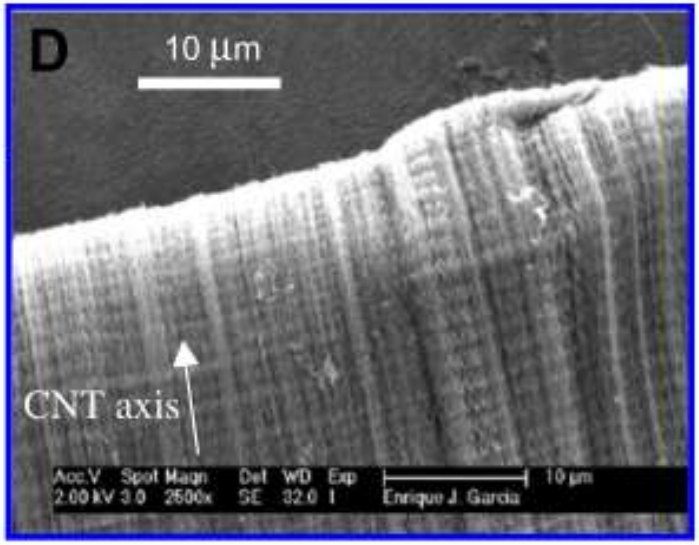
• Nanostitching

Transfer the CNTs grown on a plane substrates to prepregs CF cloth







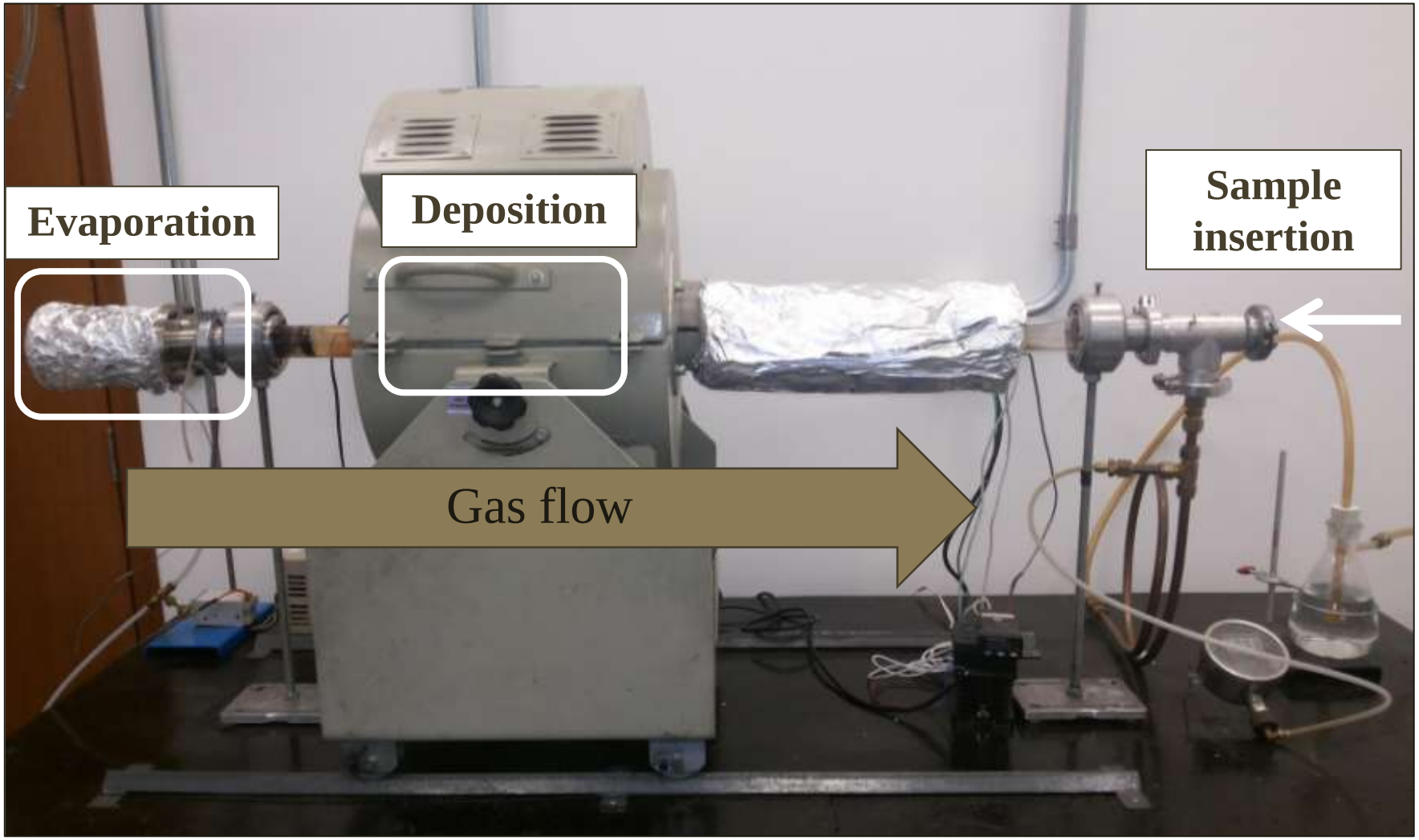


* Reference [2]

✓*Company from MIT that produces nanostitchings :* ***N12 Technologies***

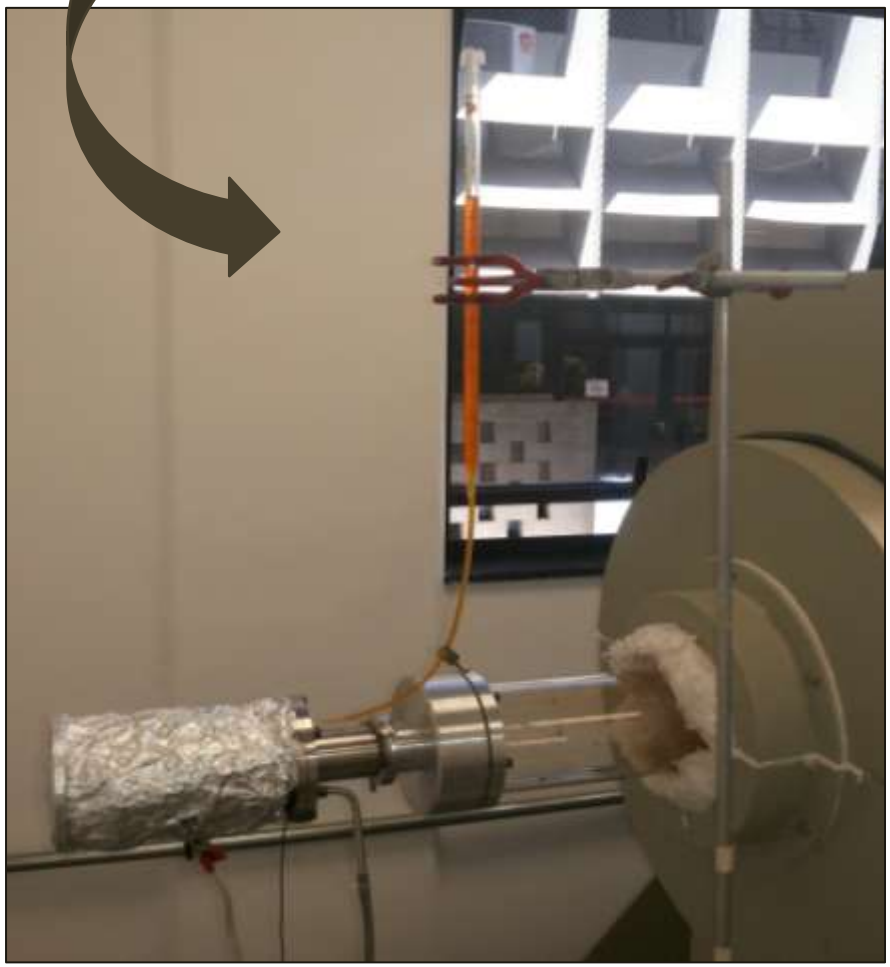
Experimental Procedure

CNTs growth reactor



Depositon Fixed Parameters

Precursor Solution → **Hexane +Ferrocene (Saturated Solution)**



- **Solution evaporation temperature:** 200 °C

- **Dripping flow**
  - ~0,2 mL / 30 sec

- **Gas flow**
  - Ar : 100 sccm
  - C_2H_2 : 5 sccm
  - CO_2 : 5 sccm

- **Pressure :** ~1 atm

Varied Parameters

➢ **Sample**

✓ CF unsized
(Toho HTS45, 12k, 7 μm)

❑ Unsizing
- 450 °C
- 15 min.
- Ar flow: 300 sccm

➢ **Exposure Time***

✓ **1 min**
✓ **5 min**
✓ **15 min**
✓ **30 min**

➢ **Heating/Growth Temperatue**

✓ **650 °C**
✓ **800 °C**

***Note** → **+ 1 min** heating after the heating/growth process.

Single Fiber Tensile Test

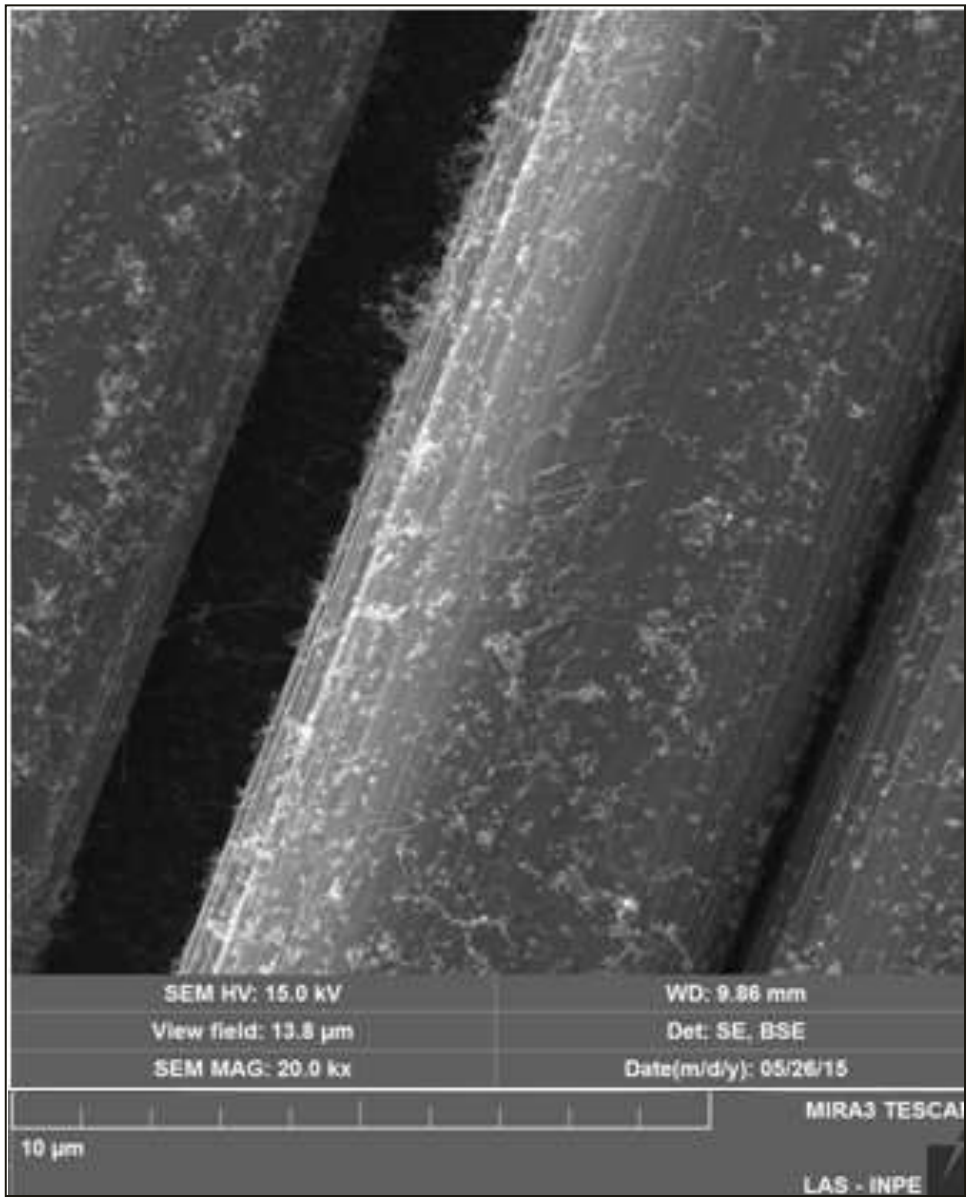
➢ CETR Tribometer

➢ Parameters

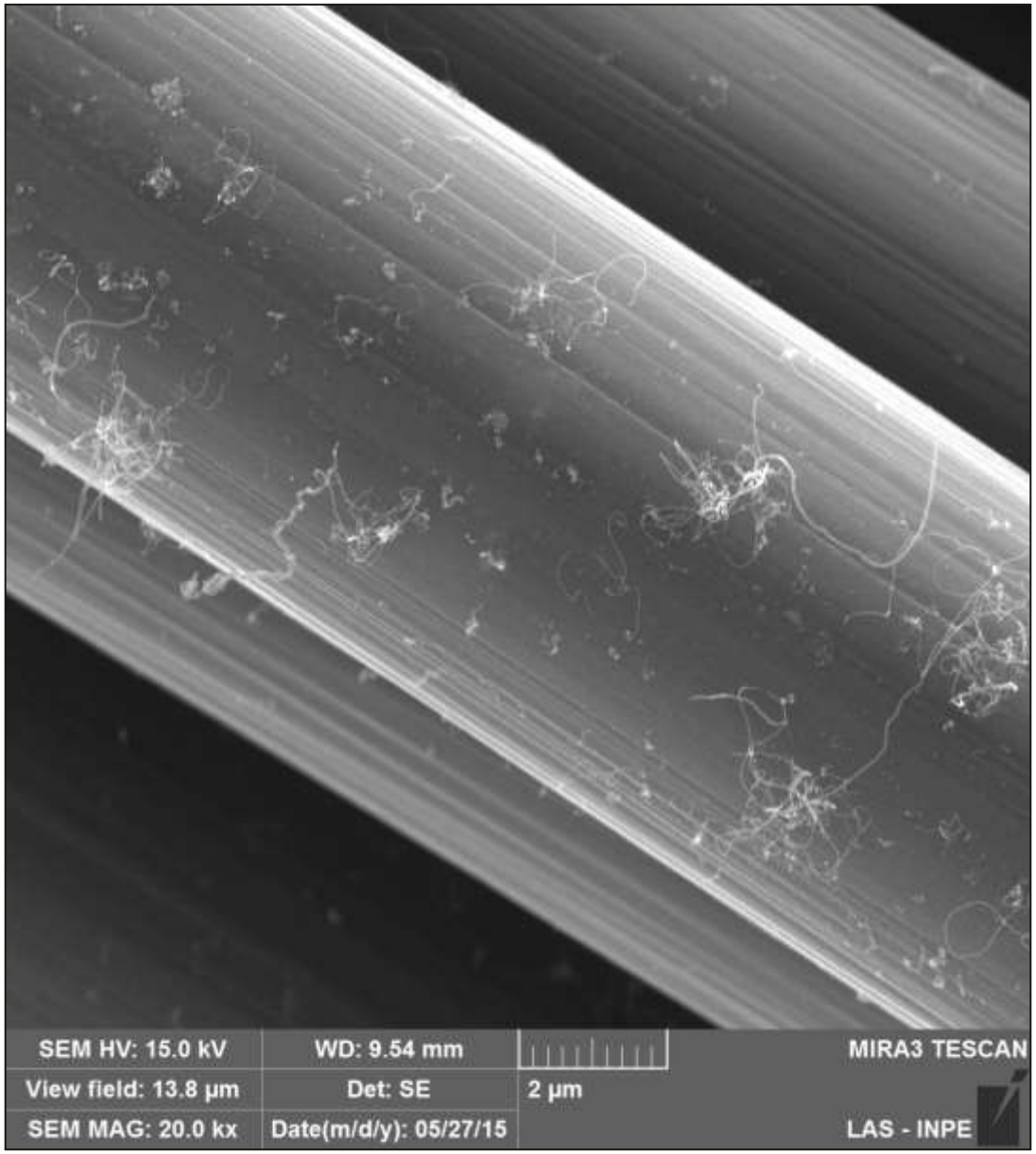
- **Load Cell** : 500 mN
- **Velocity** : 0,008 mm/s
- **Time** : ~60 sec
- **Specimen** : 2,5 cm
- ASTM C1557-14 [4]

Results and discussion

✓ CNTs deposition at 650 °C during 5 min.

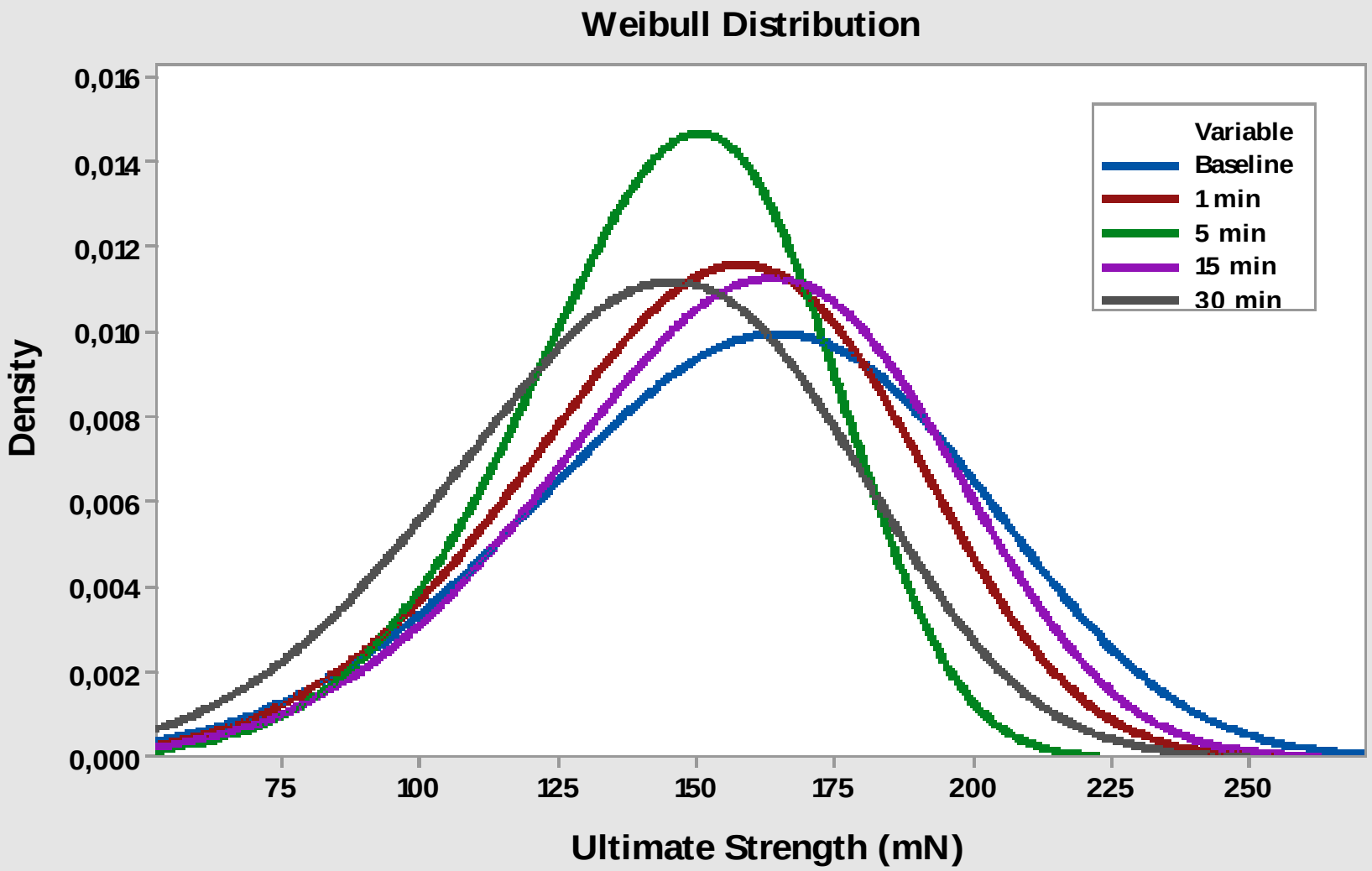


✓ CNTs deposition at 800 °C during 5 min.

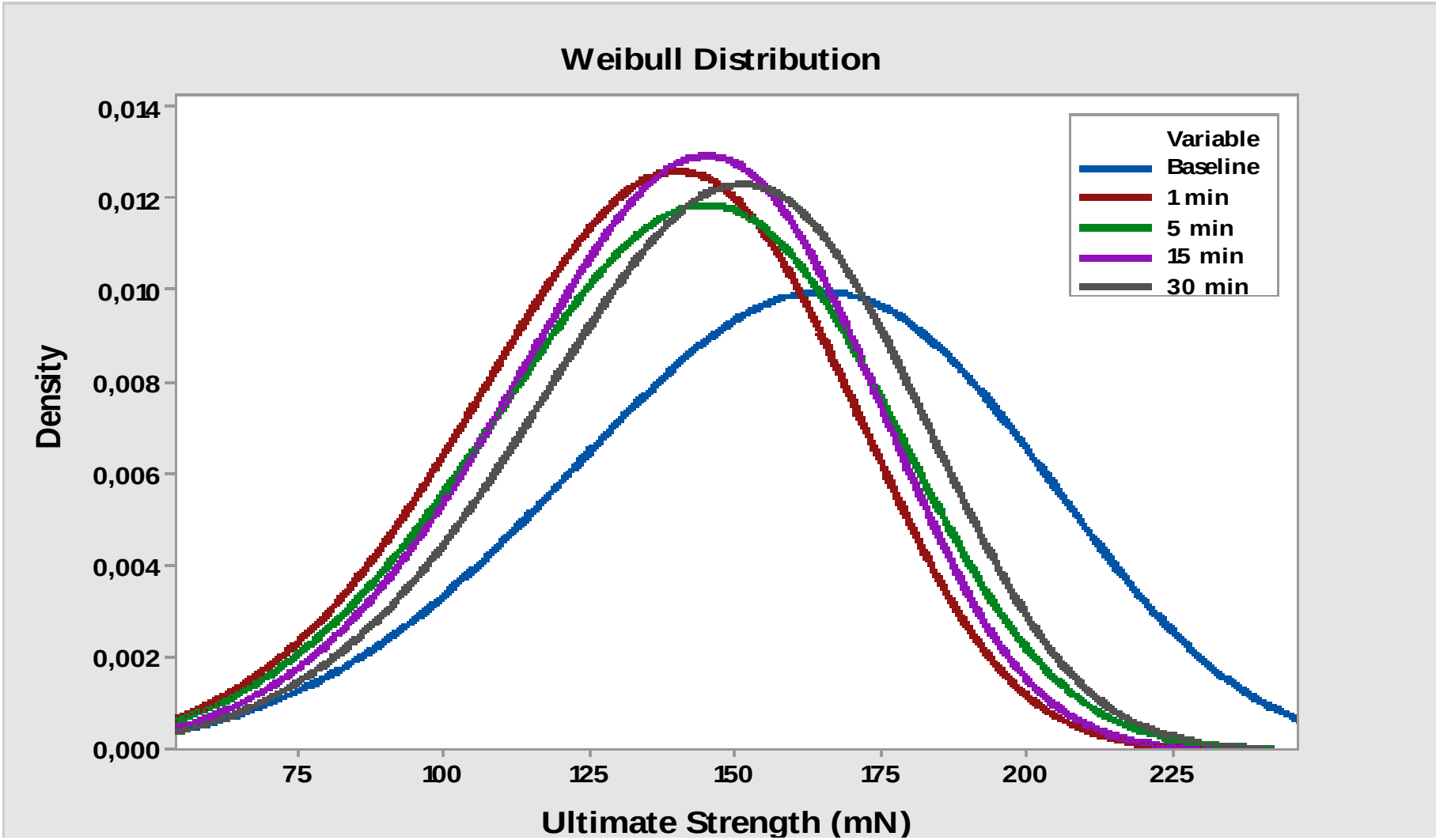


Weibull Distribution

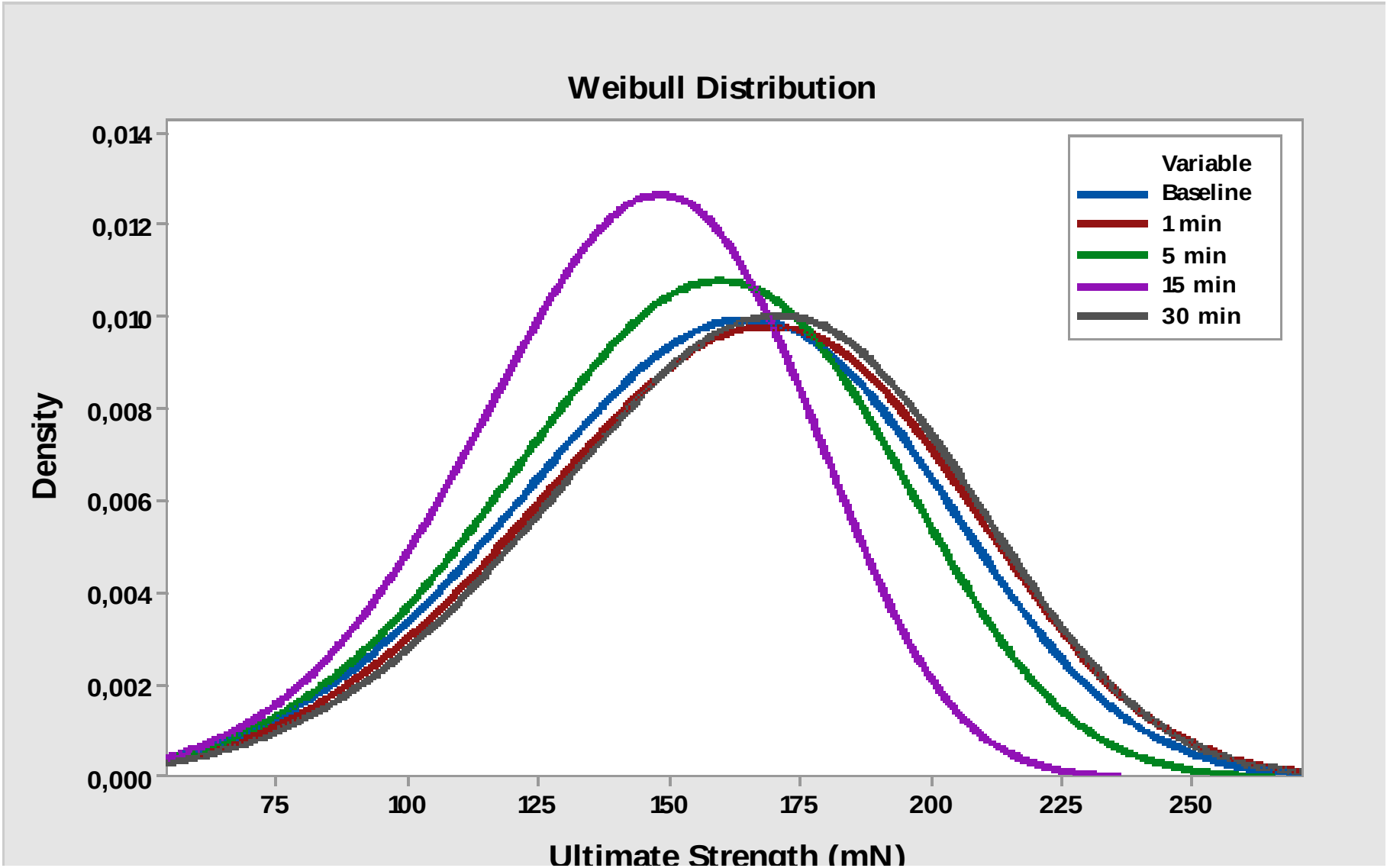
- Heating at 650 °C



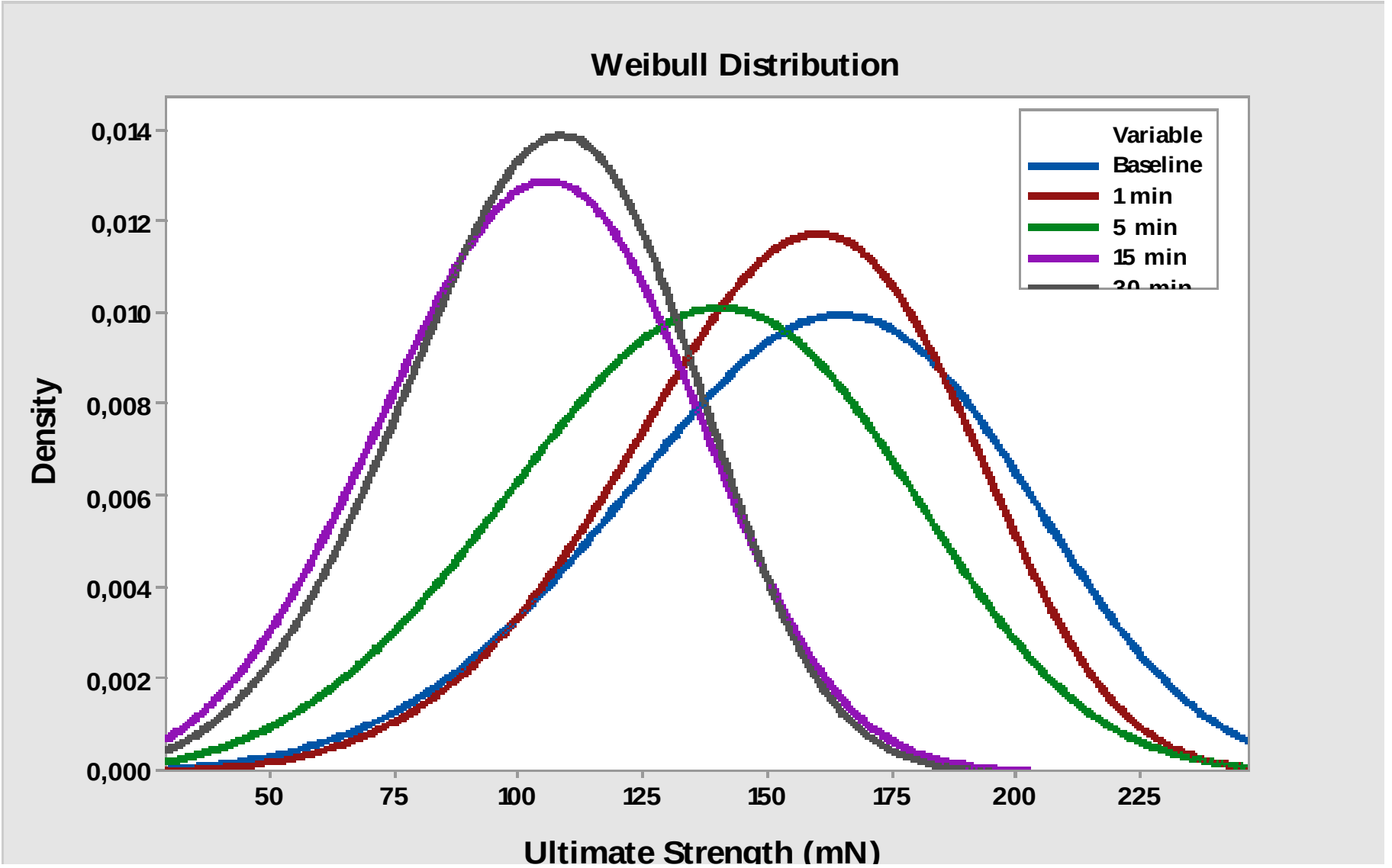
➢ Heating at 800 °C



➢ After CNTs growth at 650 °C



➢ After CNTs growth at 800 °C



Conclusions

- The SEM images shows that CNTs grows more efficiently at 650 °C, whilst at 800 °C diffusion process of the catalytic particles are activated and a homogeneous growth of CNTs is not achieved.

- The Weibull distribution showed **temperature** or **exposure time** does not influence the mechanical properties of the fiber.

- The Weibull distribution after the CNT growth process shows that at high temperature (800°C) the tensile strength decreased considerably compared to low temperatures (650°C) indicating degradation of the CF.

References

[1] De Resende, Valdirene Gonzaga et al. 2010. “Growth of Carbon Nanotube Forests on Carbon Fibers with an Amorphous Silicon Interface.” Carbon 48(12): 3655–58.

[2] Wicks, Sunny S., Roberto Guzman de Villoria, and Brian L. Wardle. 2010. “Interlaminar and Intralaminar Reinforcement of Composite Laminates with Aligned Carbon Nanotubes.” *Composites Science and Technology* 70(1): 20–28.

[3] Garcia, Enrique J., Brian L. Wardle, and a. John Hart. 2008. “Joining Prepreg Composite Interfaces with Aligned Carbon Nanotubes.” *Composites Part A: Applied Science and Manufacturing* 39(6): 1065–70.

[4] ASTM C1557-14, “Standard Test Method for Tensile Strength and Young’s Modulus of Fibers,” ASTM Standards, 2014.

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Thank You!