Processing of composites containing nanomaterials

Application of Multi Wall Carbon Nanotubes into carbon fibre reinforced prepreg composites

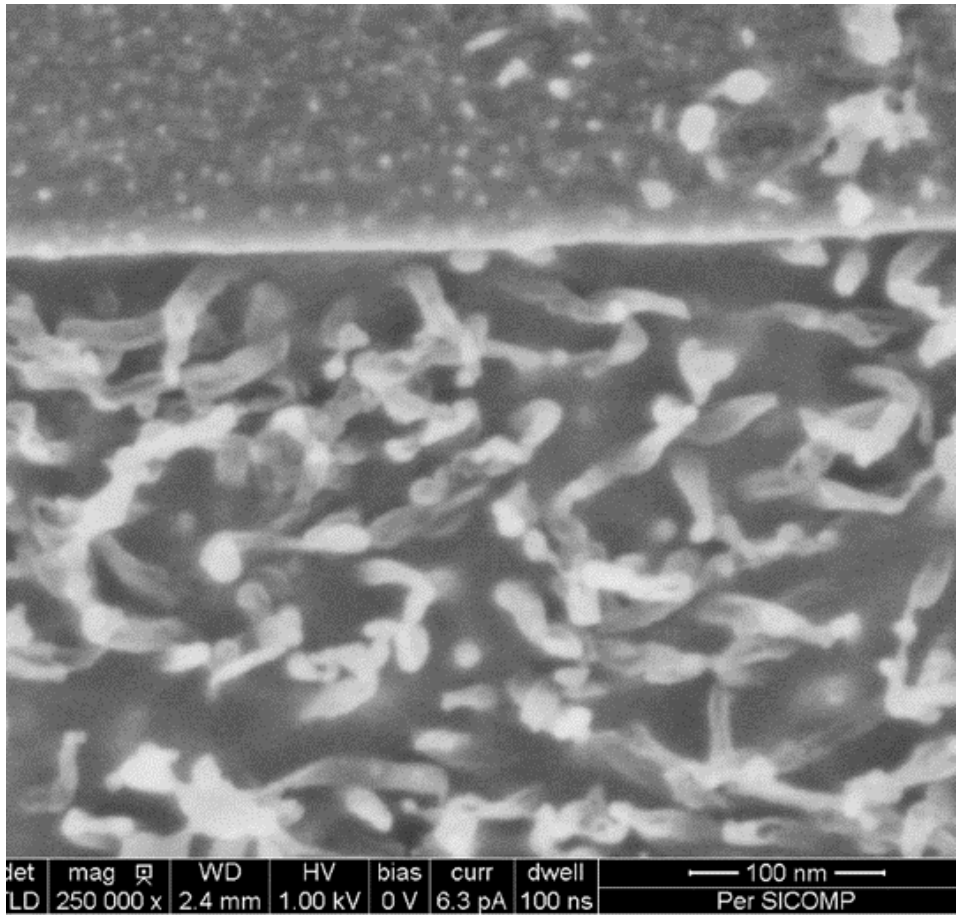
Per Hallander Saab Aeronautics

Outline

- Introduction
  - Aligned Multi Wall Carbon Nanotubes
  - Processing of composite parts
  - Process mechanisms
- Influence on forming characteristics
  - Intraply shear
  - Interply friction
- Case study effects of forming
  - Forming a double curved geometry
  - Influence of lay-up

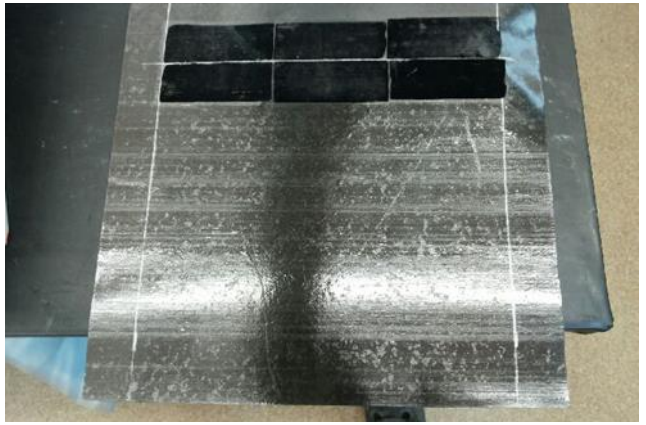
Known problems for processing Carbon Nano Tubes (CNT)

- Different ways of mixing CNTs into thermoset resins have been explored with purpose to improve physical properties:
  - Electrical conductivity
  - Thermal conductivity
  - Mechanical properties
- A well known problem with the mixing process is dispersion and distribution of CNTs into the resin.
- By using more structured CNTs, as in highly aligned multiwall carbon nano tubes (MWCNT) better results are obtained.

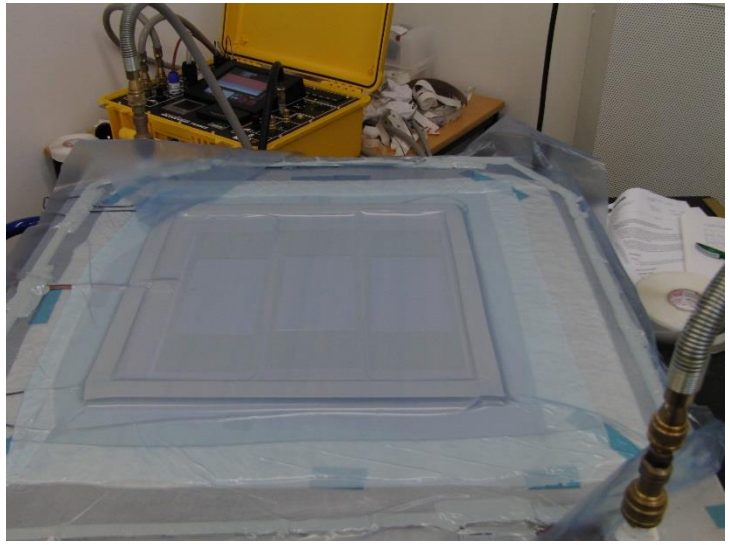


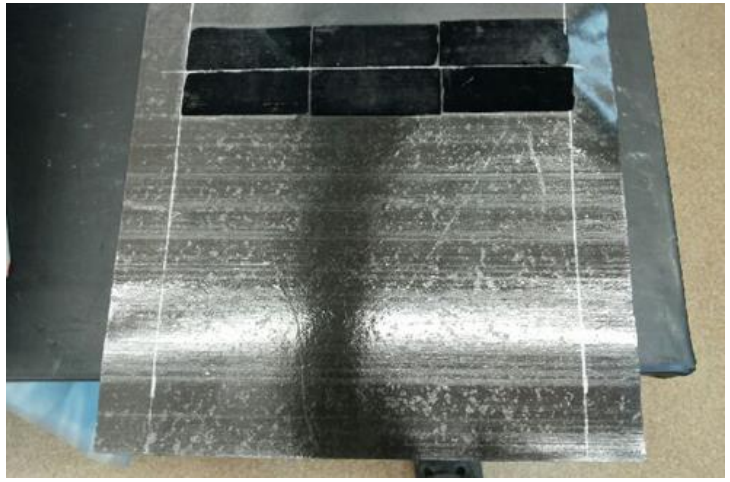
Aligned MWCNTs growth process

- Thermal catalytic chemical vapor deposition (CVD) on silicon wafers
- Using a thin catalyst layer of Fe/Al2O3 deposited by electron beam evaporation
- CNT growth in tube furnace using ethylene as the carbon source
- MWCNT:s provided by MIT and N12
- Mat with out-of-plane aligned MWCNTs transferred to a carbon/epoxy prepreg surface
- Used as an interlayer in a stacked prepreg laminate



Transfer process



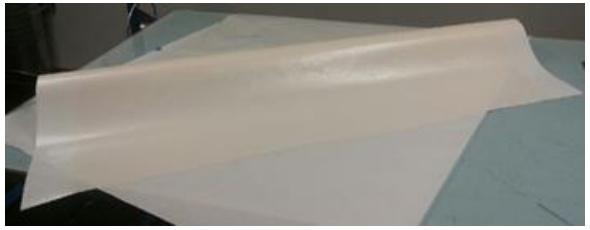


- Use of repair box and heater blank.
- Controlled heat-up rate, cooling rate and vacuumlevel.
  - Heat-up
  - Apply reduced vacuum level
  - Cool down

The most modern aircrafts are built of thin layers of epoxy pre-impregnated carbon fibres

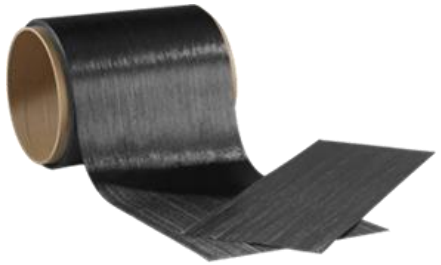
Fiber

+

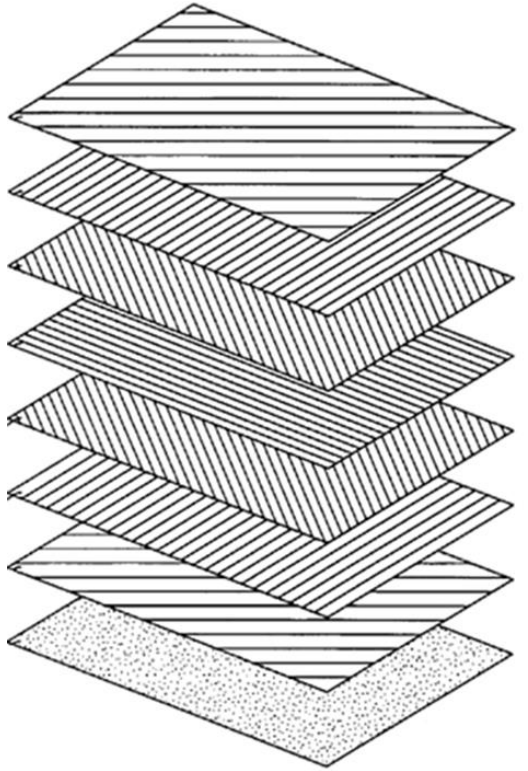


Resin film

Prepreg

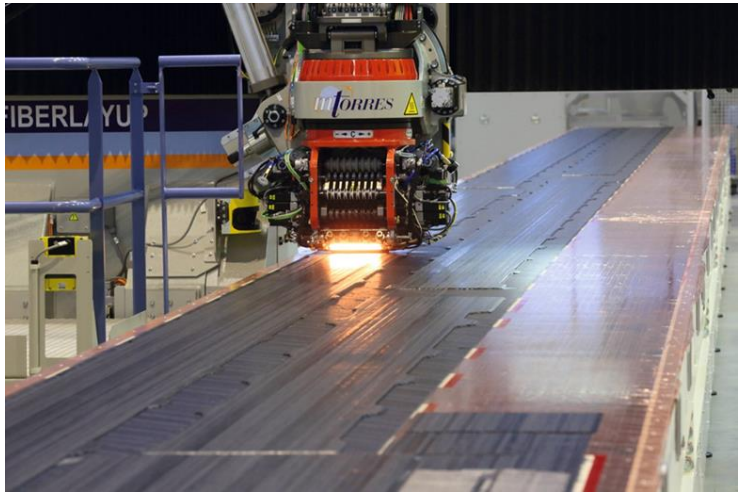


Uni-directional or woven
~57% fibre volume content
180°C systems



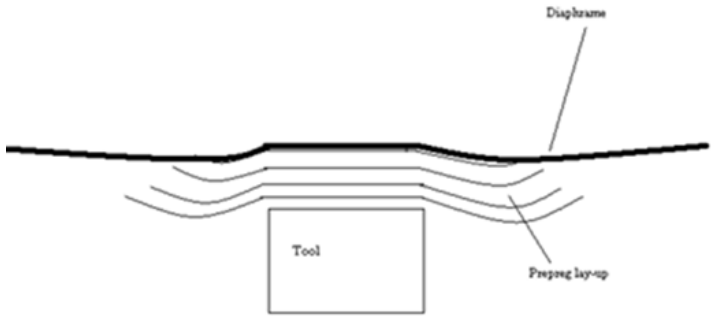
Multi-layer-stack

Hand lay-up or automated prepreg lay-up



Fibre Placement (AFP)
Courtesy of Jan Kako, Airbus

Vacuum Forming

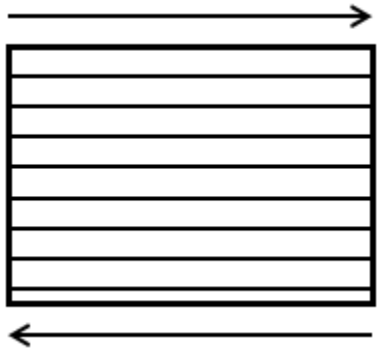


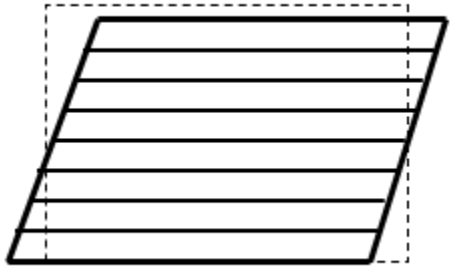
Vacuum forming could be performed at elevated temperatures – Hot Drape Forming (HDF)

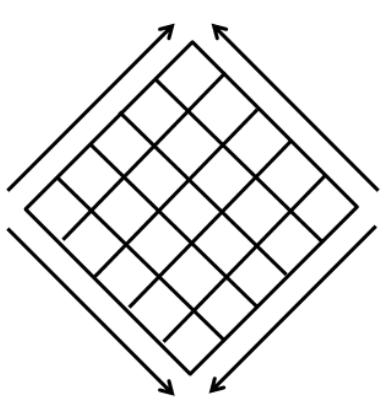
Cure process

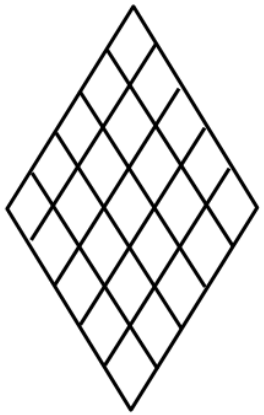
- Autoclave cure
  - Cure temperature 180 ˚C
  - Pressure 1 to 7 bar

Important forming mechanisms

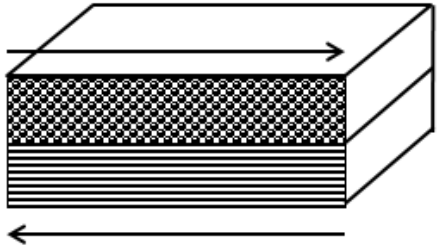


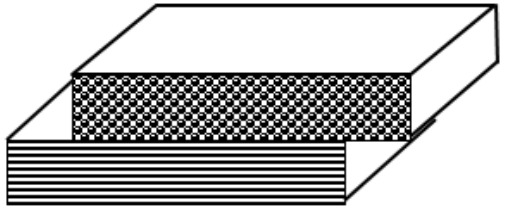




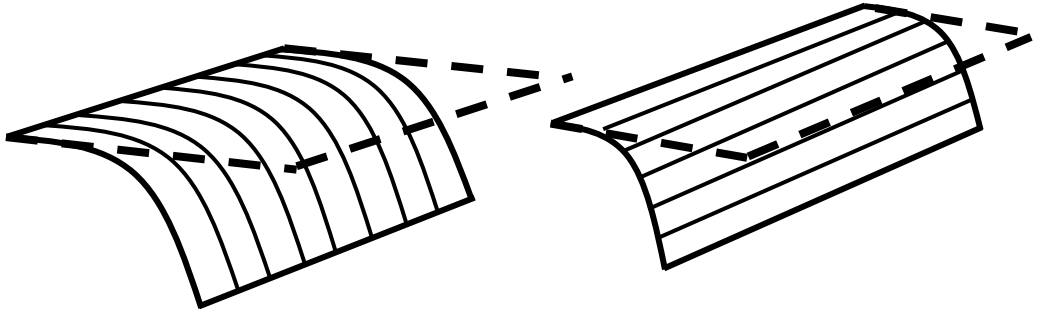


In-plane intraply shear



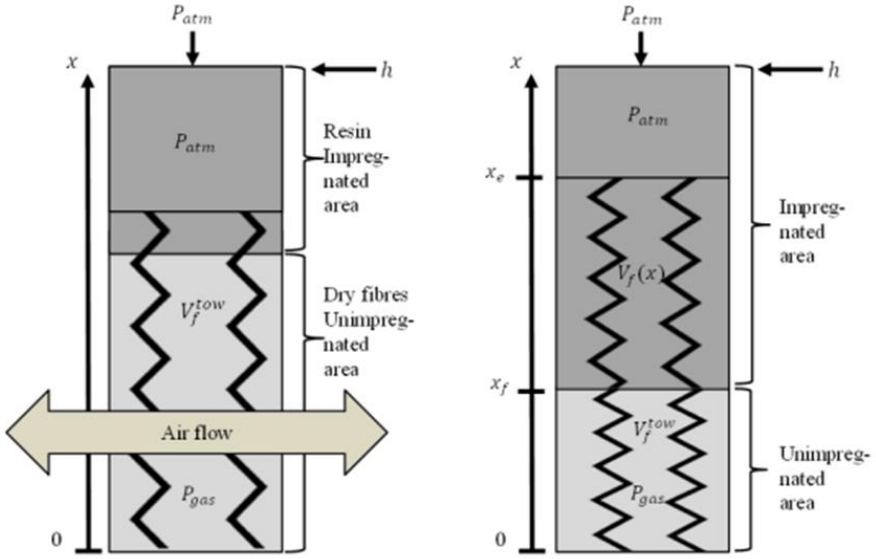


Interply friction – between layers



Out-of-plane bending

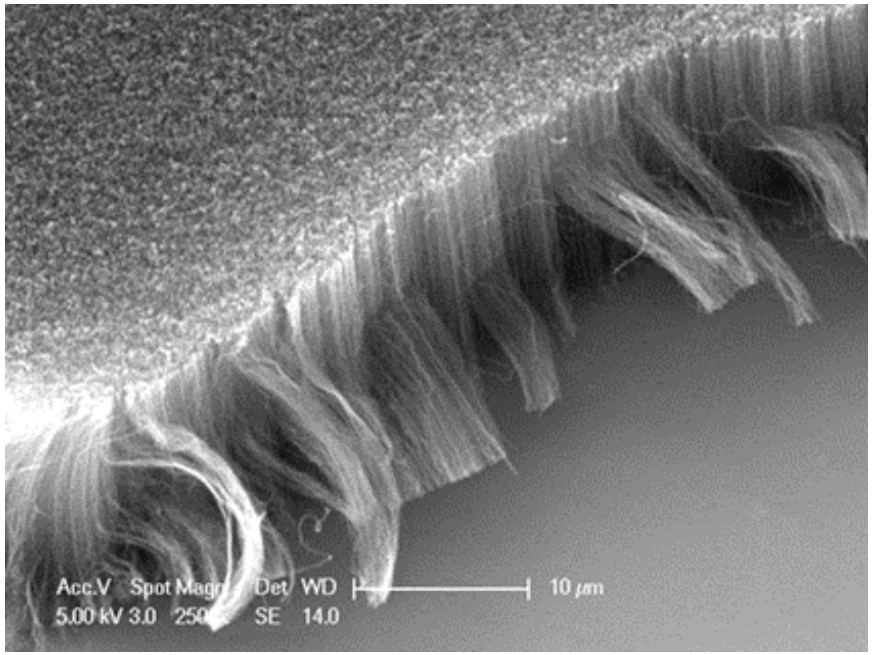
Consolidation during forming and cure process



- Fibre bed compaction
- Resin infiltration

- Resin bleed out flow
- Squeeze flow
  - in-plane material movement developed by a pressure gradient

Influence on forming characteristics

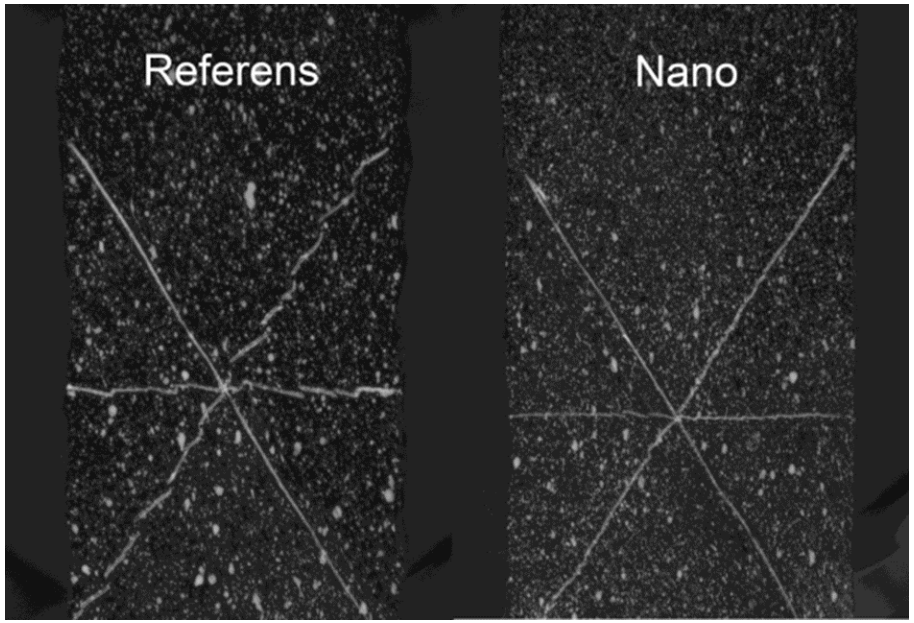


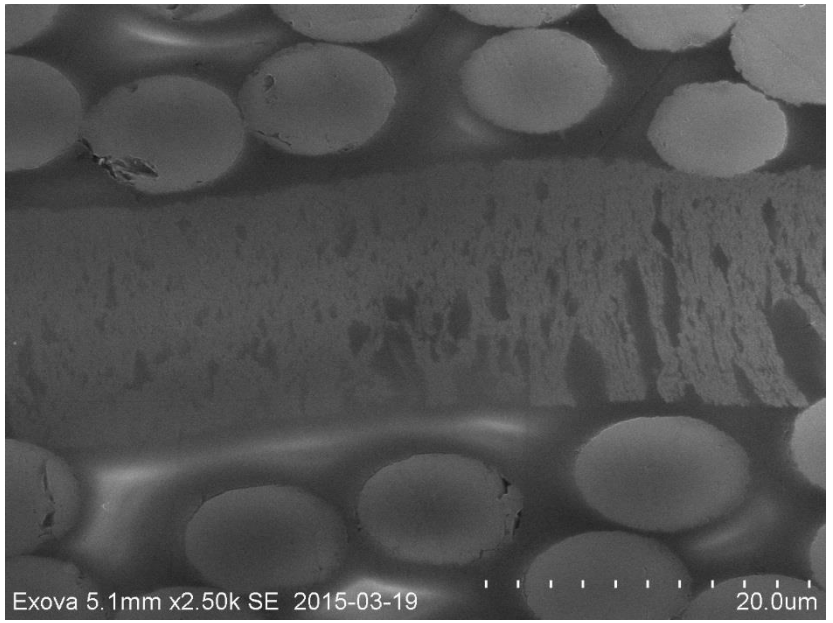
Aligned MWCNT
Courtesy of Roberto Guzmán Villoria

- Intraply shear
- Interply friction

- Interlayer materials
  - MWCNT
  - 10 g/m2 nylon 6.6 veil

Influence on forming characteristics





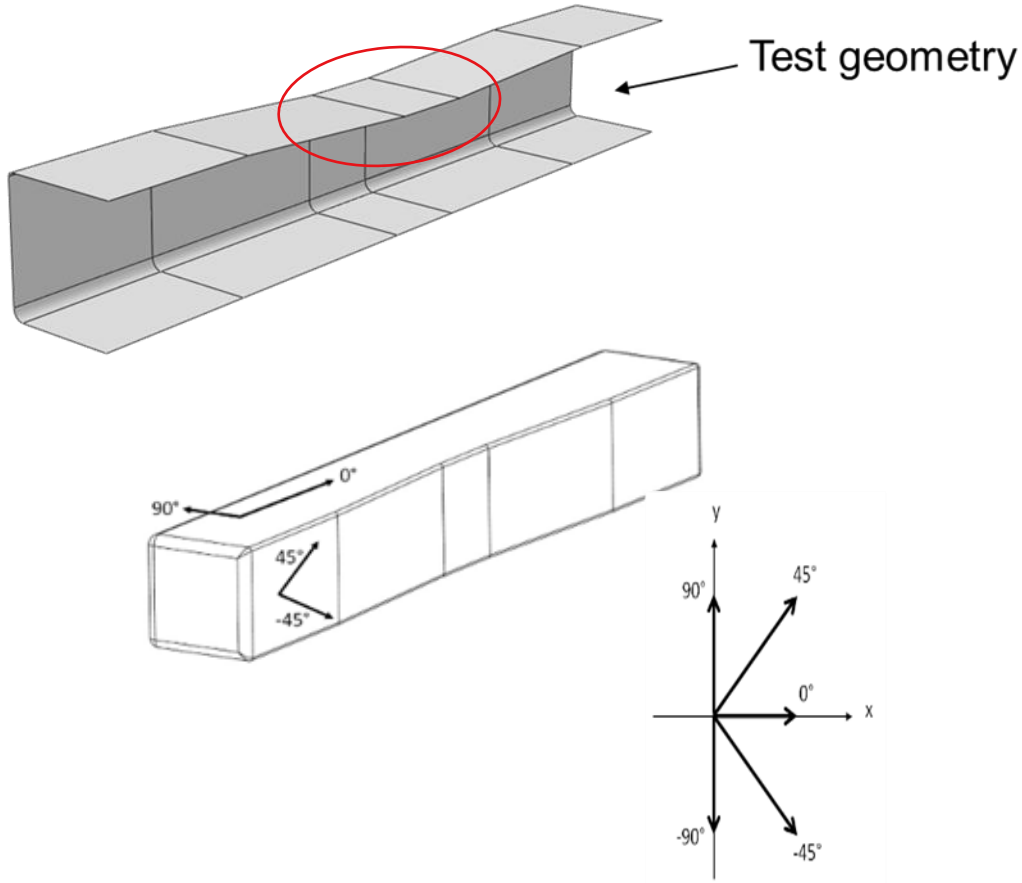
Near ideal intra ply shear for MWCNT samples

Veil samples separated

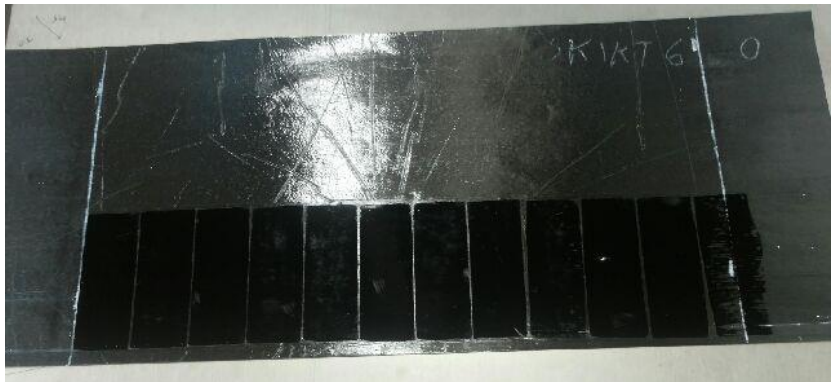
300-400% increase of interply friction for samples with both interlayer materials

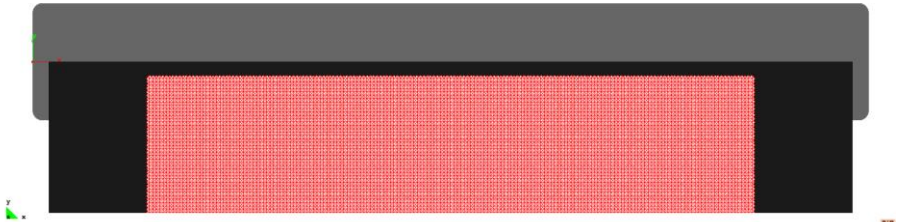
Case study effects of forming

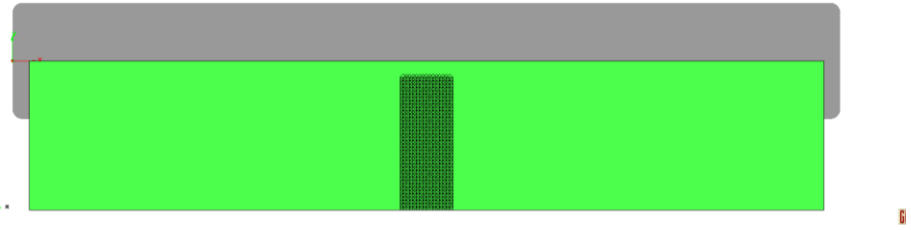
- Spar geometry
  - Spar length [mm] 480
  - Web width [mm] 70
  - Flange length [mm] 55
  - Transition zone length [mm] 125
  - Transition zone depth [mm] 6.25
  - Nominal thickness [mm] 1
  - Radius recess flange [mm] 2
  - Radius Straight flange [mm] 6

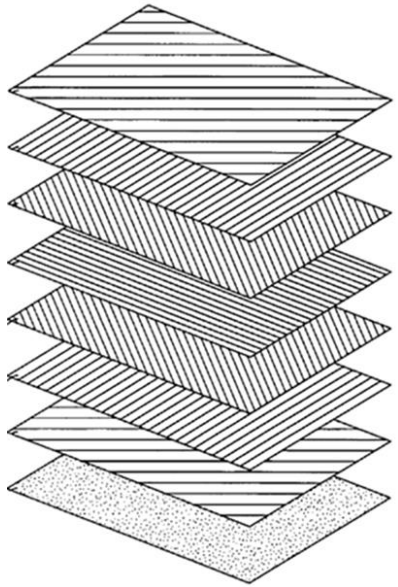


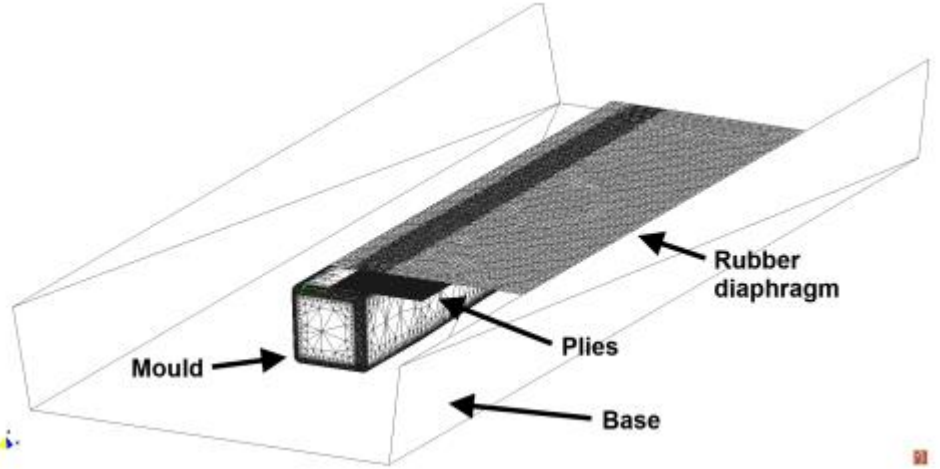
MWCNT positioning

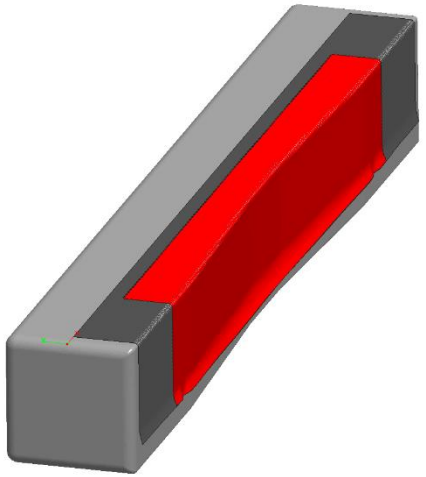




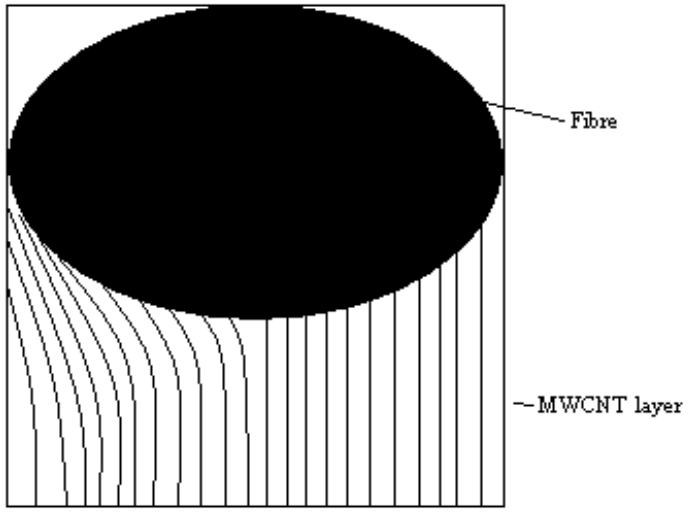


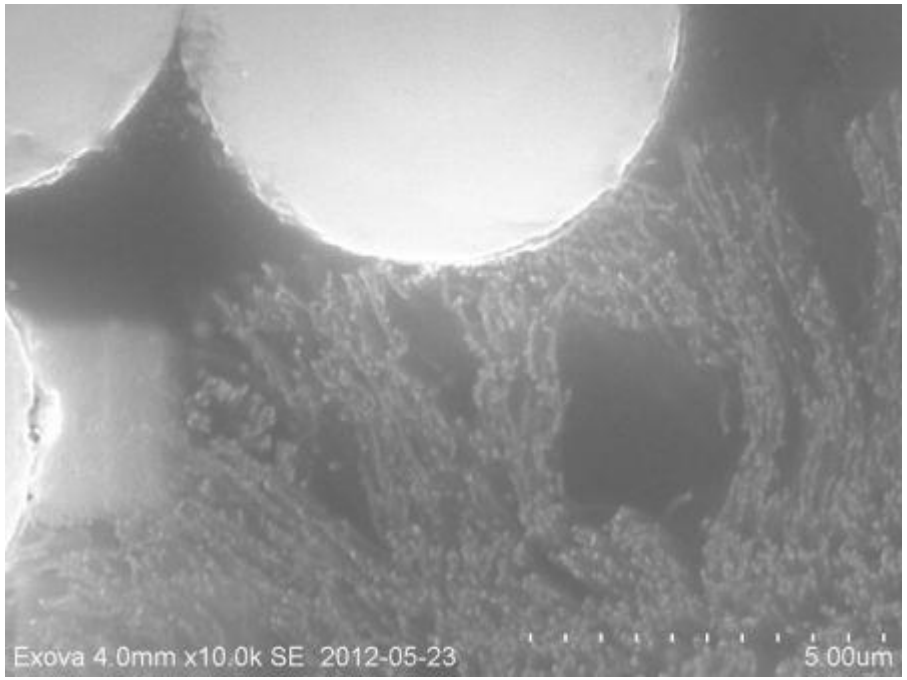




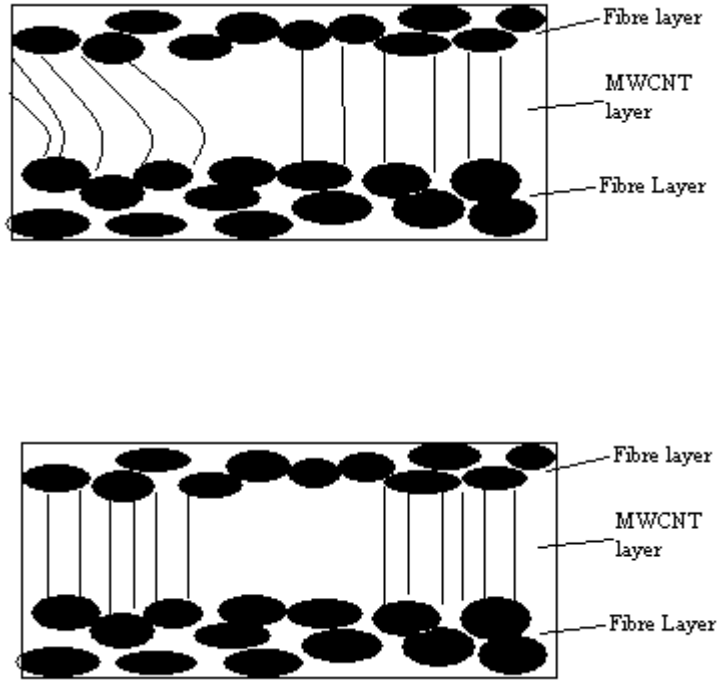


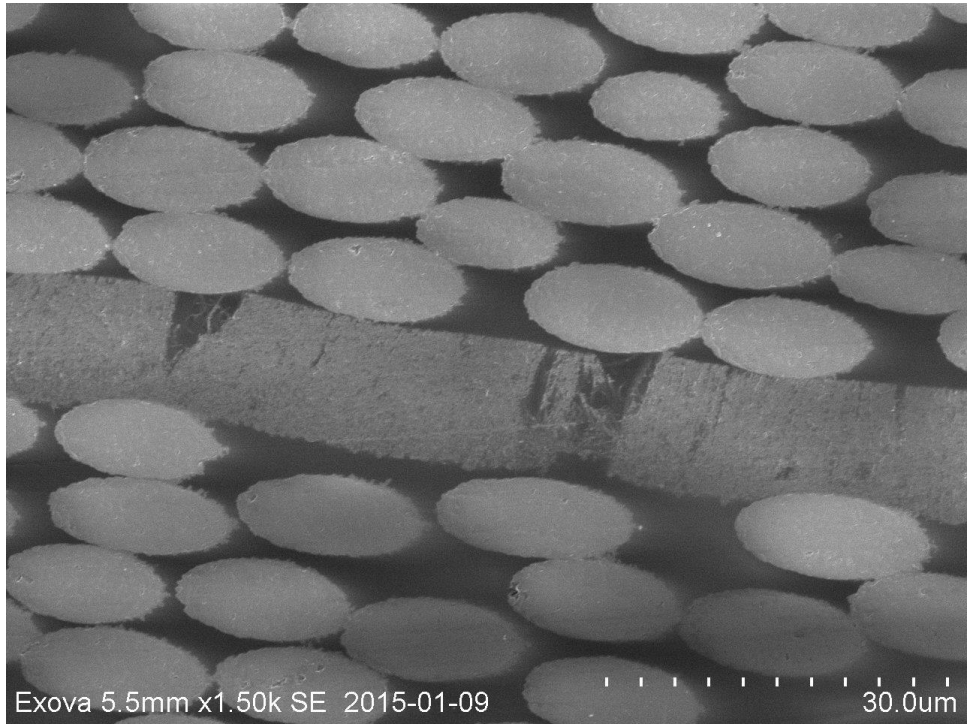
Process effects on MWCNT interlayer



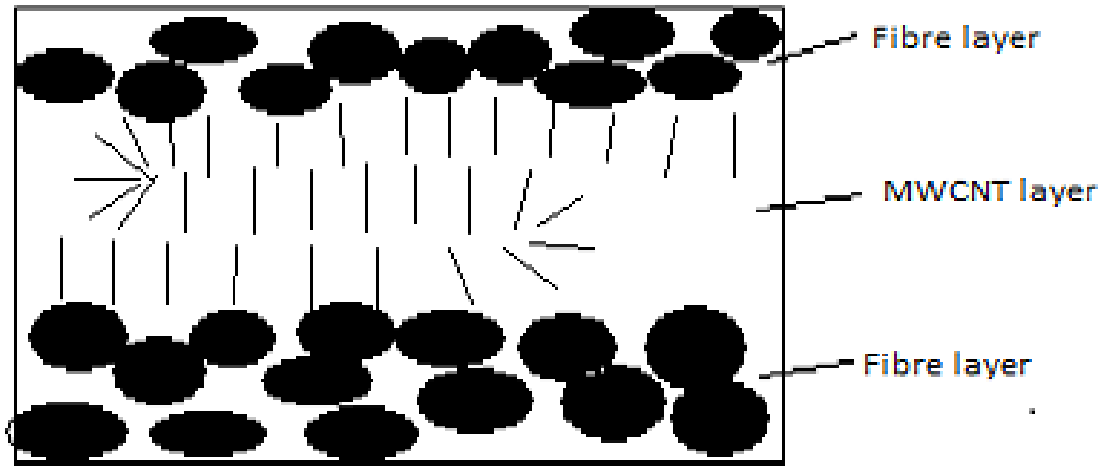


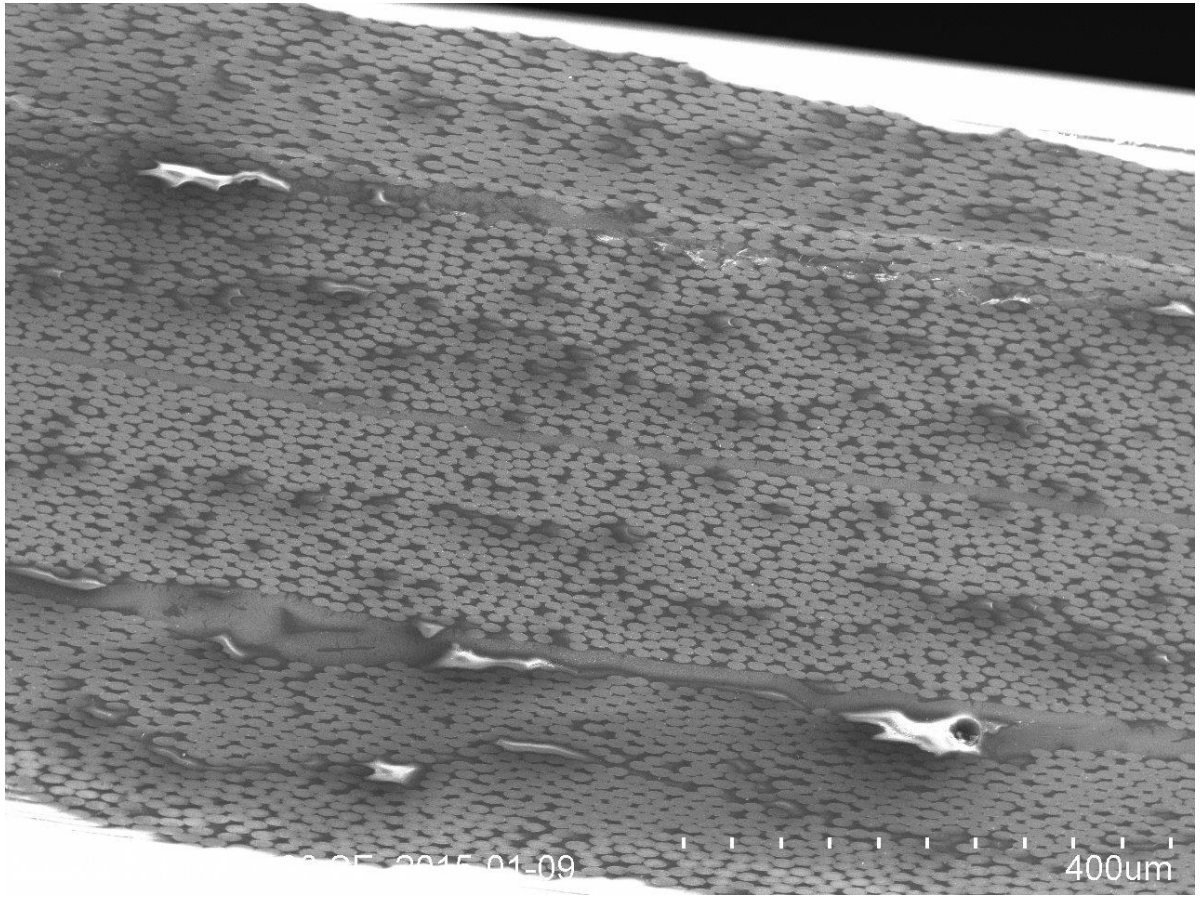
Process effects on MWCNT interlayer





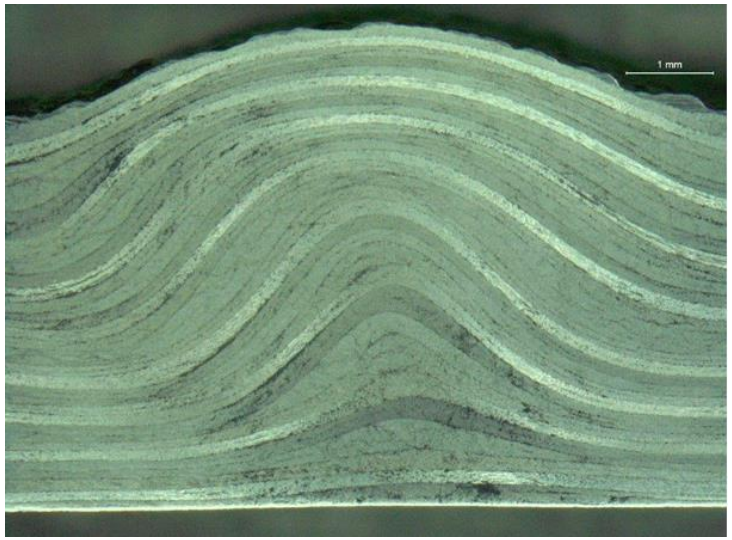
Process effects on MWCNT interlayer

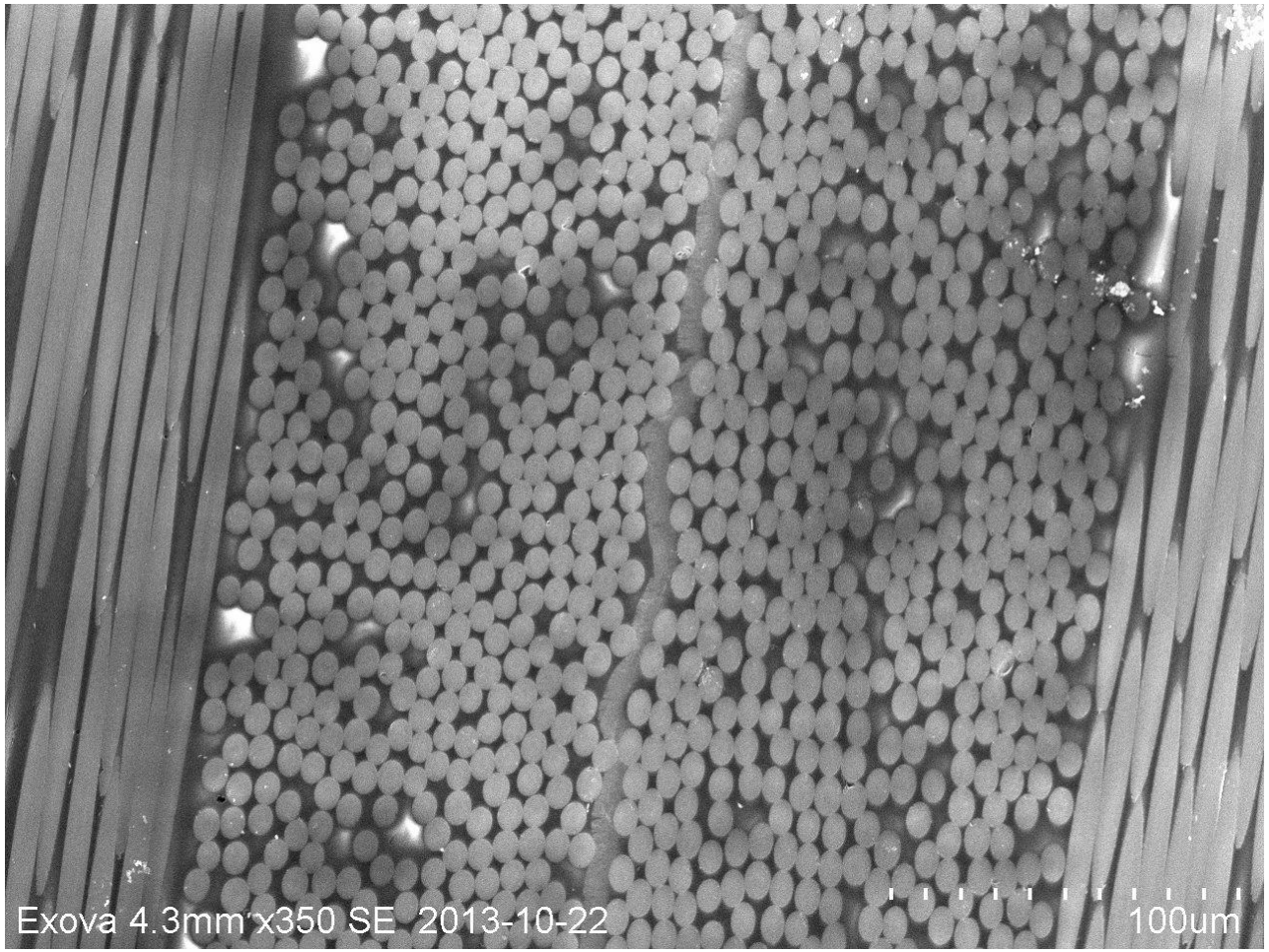




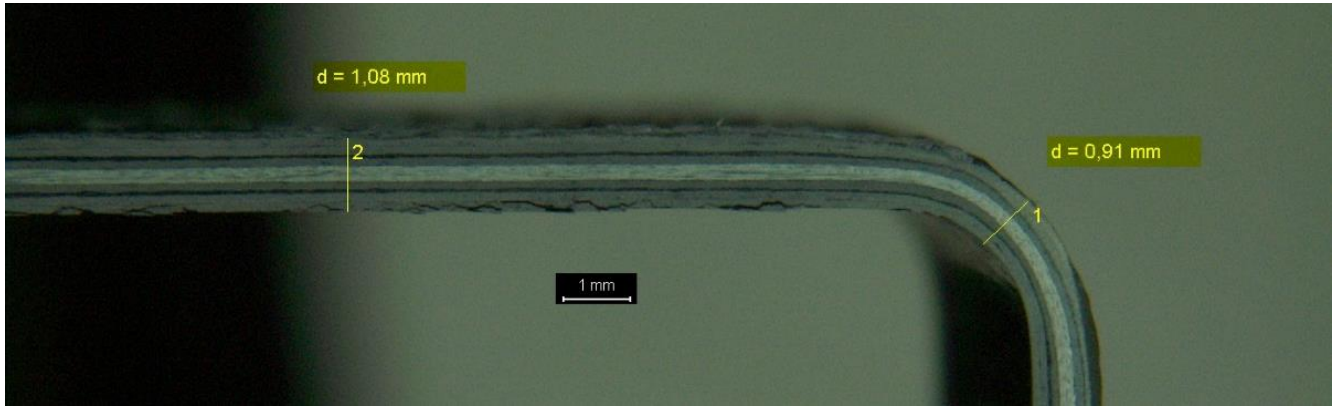
Sensitivity to Squeeze flow

- Pressure gradient often appears in:
  - Radius
  - Ramp areas
  - Areas with dispositioned tooling
  - Areas with hanging bag material in the cure assembly

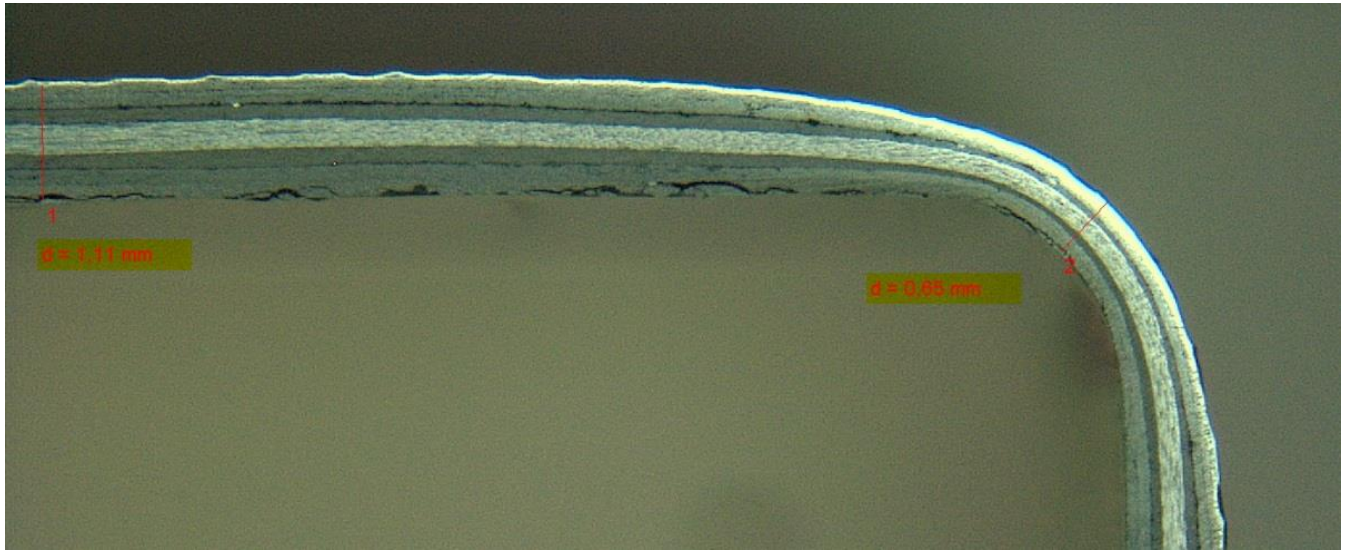




Radius thinning with modified interlayers



Veil interlayer



MWCNT interlayer

Wrinkle free forming with tailored interlayers

Using interlayer modifiers

- MWCNT

Tailoring the

[45]/[-45] and [0]/[90] interlayers

of a $[(45,-45,0,90)]_s$ lay-up

MWCNT in the [45]/[-45] and [0]/[90] interlayers

Wrinkle free forming with tailored interlayers

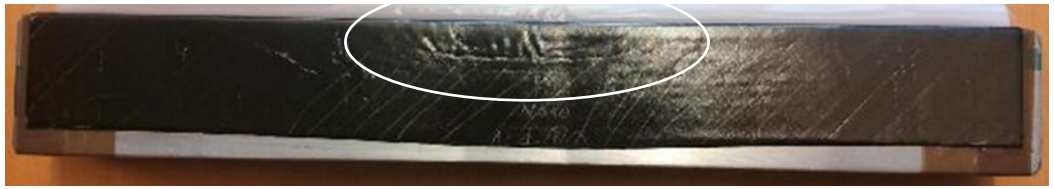
Using interlayer modifiers

- MWCNT

Tailoring the

[45]/[-45] and [0]/[90] interlayers

of a $[(45,-45,0,90)]_s$ lay-up



MWCNT in the [-45]/[0] interlayers

MWCNT in the [45]/[-45] and [0]/[90] interlayers

Locally increased friction is more important than globally decreased friction!


Thank you for your attention!