

Out of autoclave processing

-Advanced Composite processing-

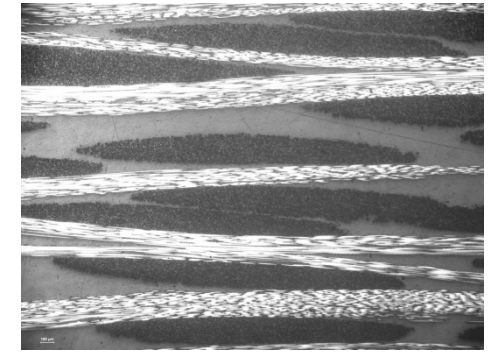
Mario Danzi



Process requirements

- Laminate requirements for aerospace application

60 %	Fiber volume content
< 0.5 %	Void volume content
40 %	Resin volume content



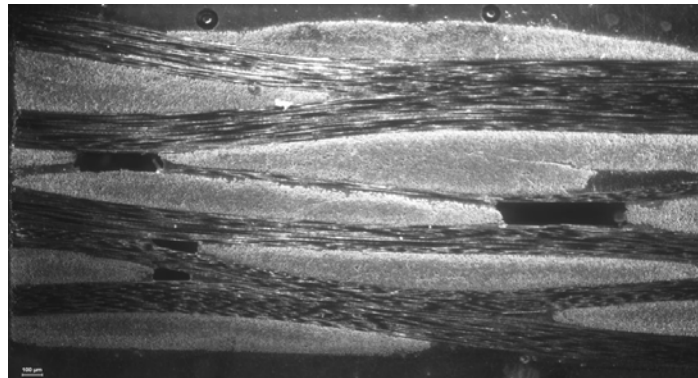
CFRP sample with
approximately 50% FVC

- Typical value for different manufacturing processes

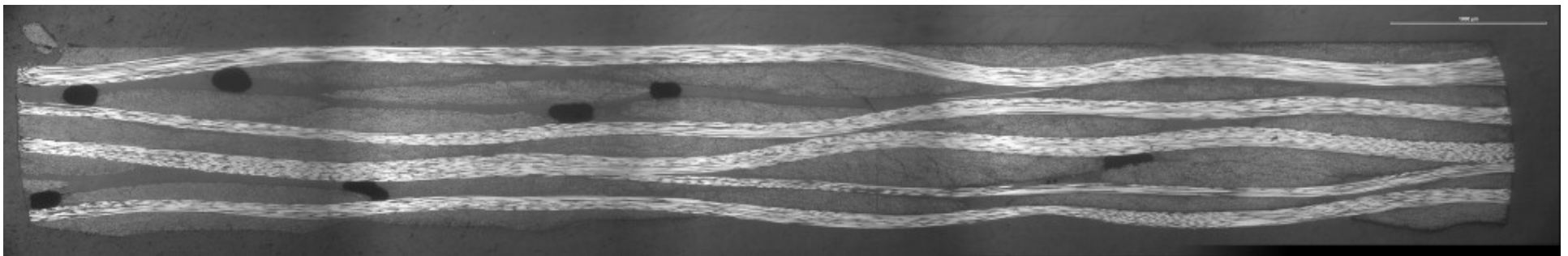
Process	Void Content	Fiber Content
Hand layup	5 – 15 %	~ 50 %
VARI	5 – 10 %	45 – 55 %
RTM	1 – 5 %	50 – 65 %
Autoclave prepreg	0 – 1 %	55 – 65%
OoA prepreg	0.5 – 3 %	50 – 60%

Process requirements

- Examples of voids in CFRP laminates

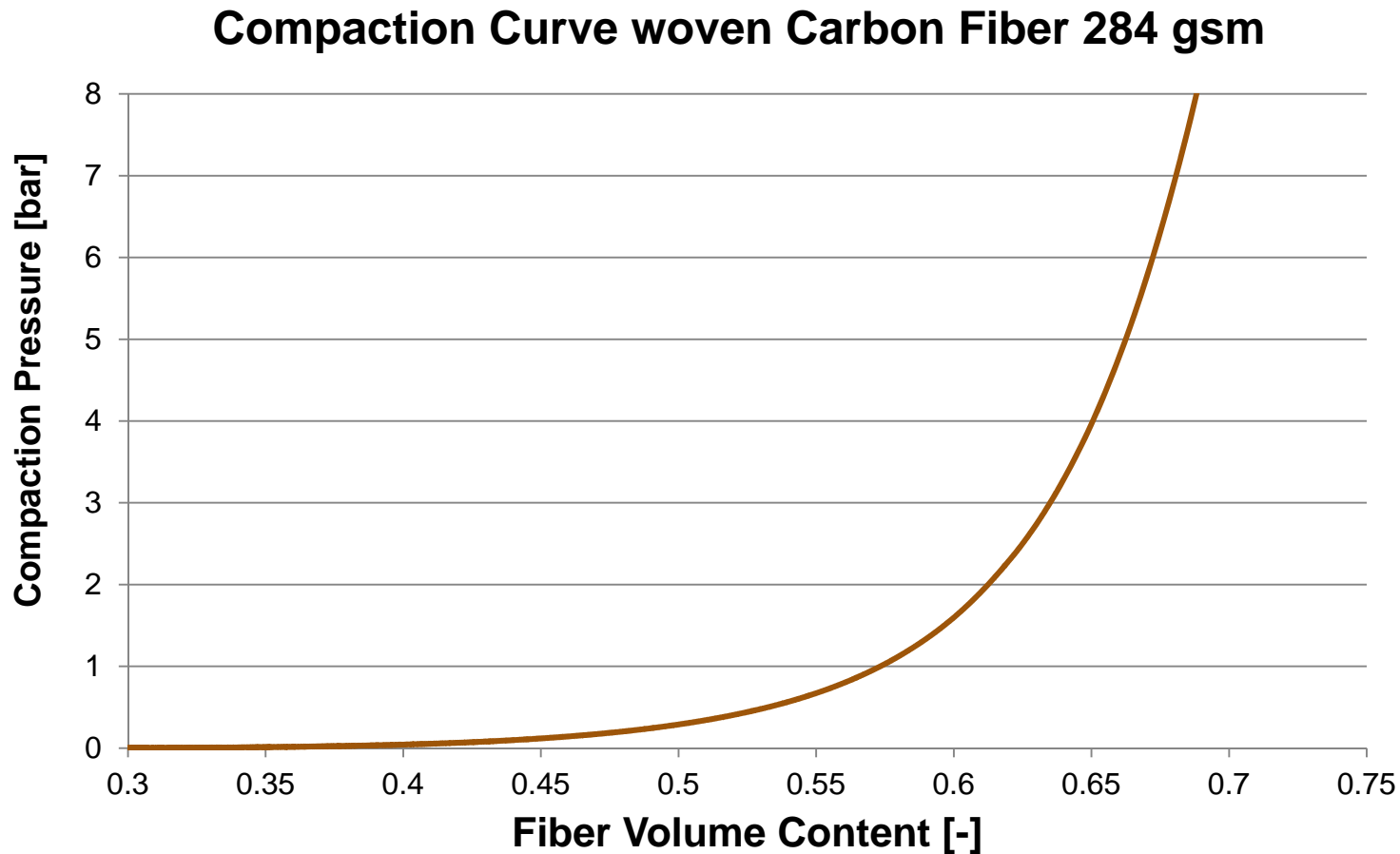


Microscopy of prepreg laminate with resin lack.



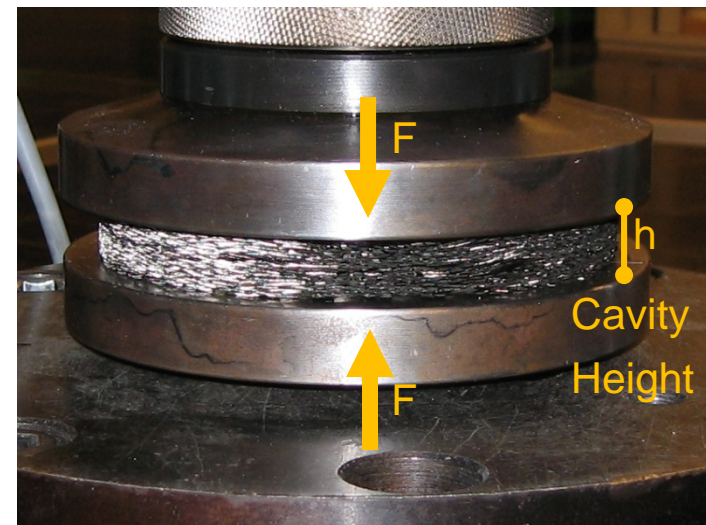
Microscopy of laminate manufactured in VARI process.

Fiber Bed Compaction

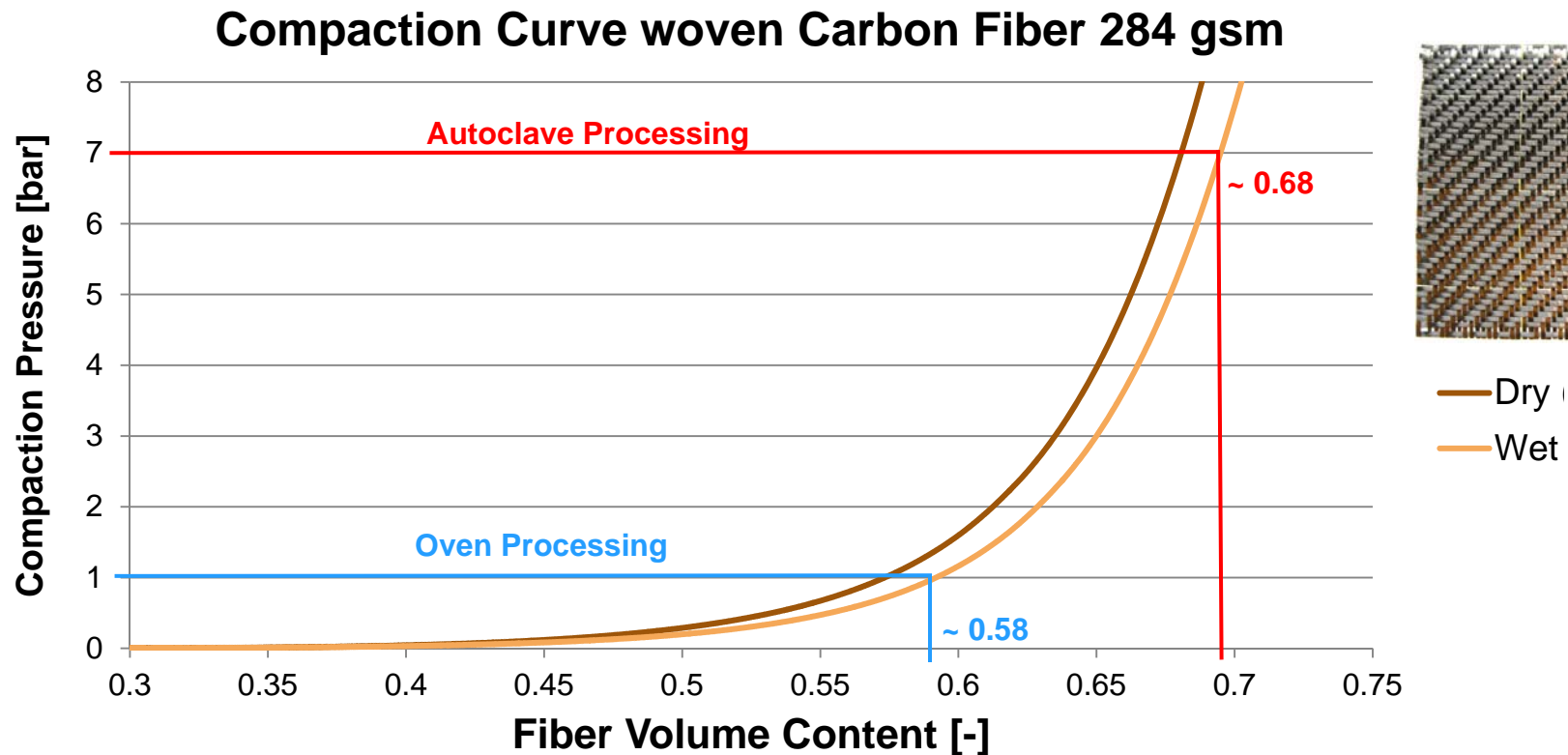


Fiber Bed Compaction

- 20 layer of fabric are compressed between two plates in the Zwick machine. The displacement is kept as low as possible (around 0.1 mm/min) to reduce visco-elastic and fiber relaxations effects.
- The test is performed in „dry” and “wet” state. The wet fabric is impregnated with silicon oil (0.1 Pa*s).



Fiber Bed Compaction



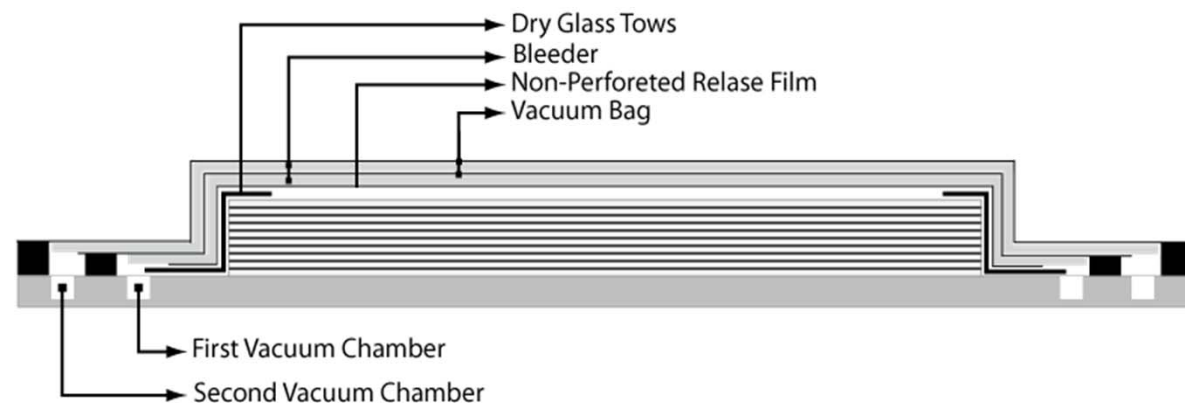
Wetting of the fabric increases the slipping of fibers and thus the compressibility. Capillary effects may cause cohesive forces between the fibers and thus a reduction in volume.

OoA processes

■ OoA prepreg process:

1. Layup, intermediate debulking
2. Debulking
3. Heating to curing temperature
4. Curing process
5. Heating to post-cure temperature
6. Post-cure process

-> Adaption to mould shape and first ply compaction



Entrapped air and volatiles have to be extracted prior to gelation !!!!

OoA processes

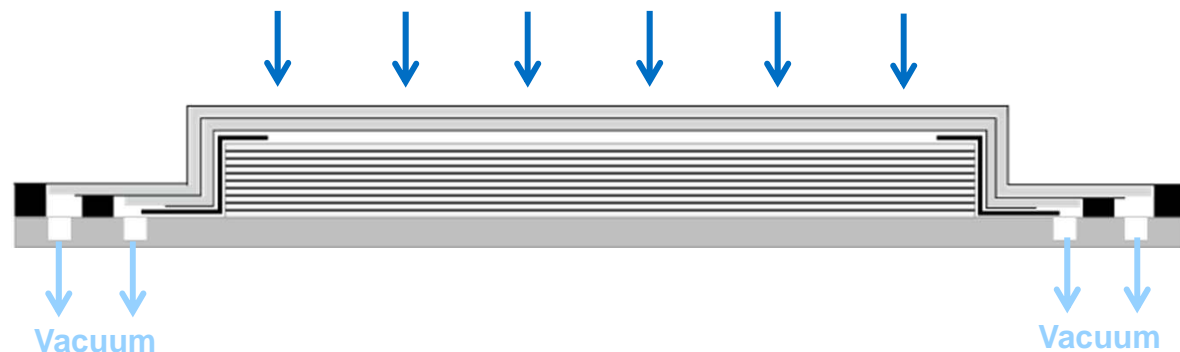
■ OoA prepreg process:

1. Layup, intermediate debulking
2. Debulking
3. Heating to curing temperature
4. Curing process
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-> Air extraction and ply compaction

Extract as much air and volatiles as possible.

Excessive debulking should be avoided because could close air channels in the laminate stack.



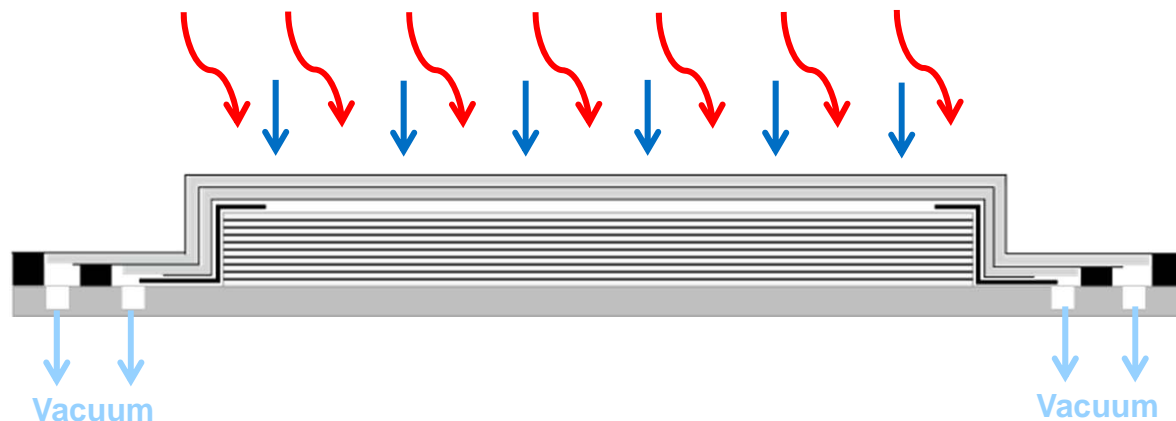
Entrapped air and volatiles have to be extracted prior to gelation !!!!

OoA processes

■ OoA prepreg process:

1. Layup, intermediate debulking
2. Debulking
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4. Curing process
5. Heating to post-cure temperature
6. Post-cure process

-> Air extraction, lower resin viscosity



Entrapped air and volatiles have to be extracted prior to gelation !!!!

OoA processes

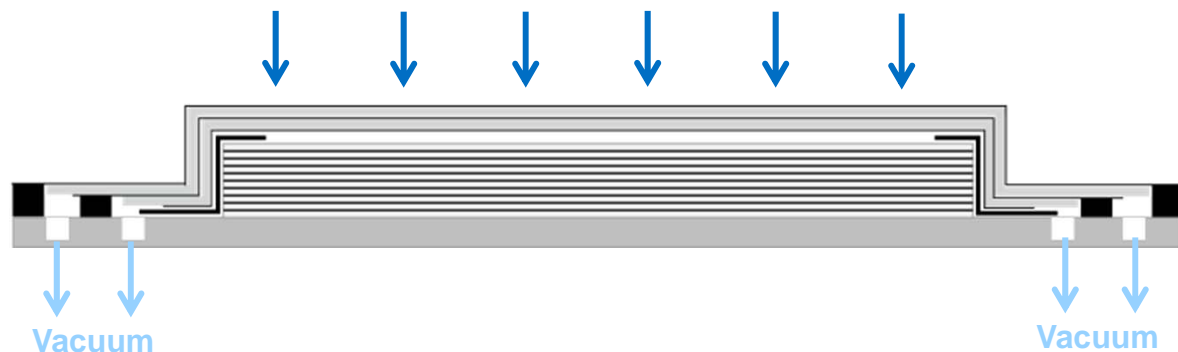
■ OoA prepreg process:

1. Layup, intermediate debulking
2. Debulking
3. Heating to curing temperature
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5. Heating to post-cure temperature
6. Post-cure process

-> Air extraction until gelation

After gelation no more air can be extracted

Typical cure temperature around 130°C or lower.



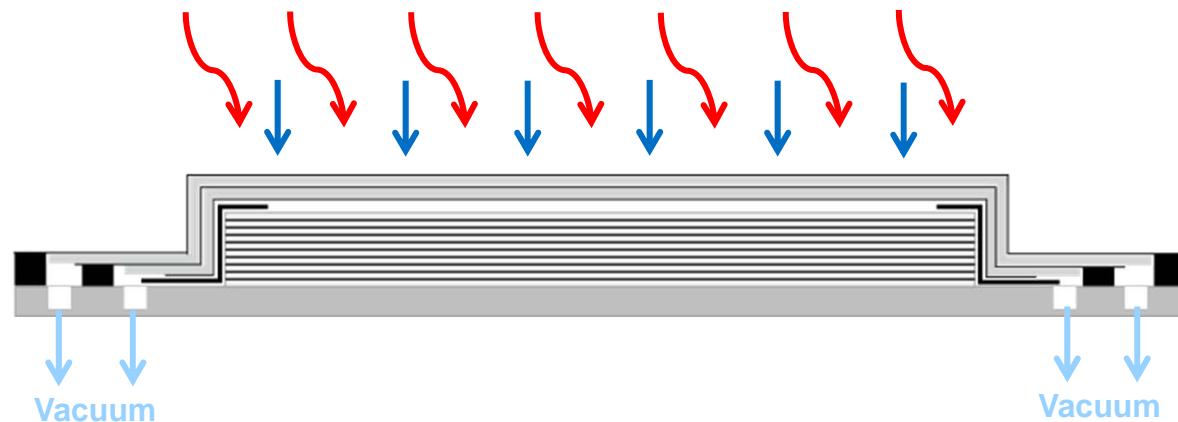
Entrapped air and volatiles have to be extracted prior to gelation !!!!

OoA processes

■ OoA prepreg process:

1. Layup, intermediate debulking
2. Debulking
3. Heating to curing temperature
4. Curing process
5. Heating to post-cure temperature
6. Post-cure process

-> No more air extraction is possible



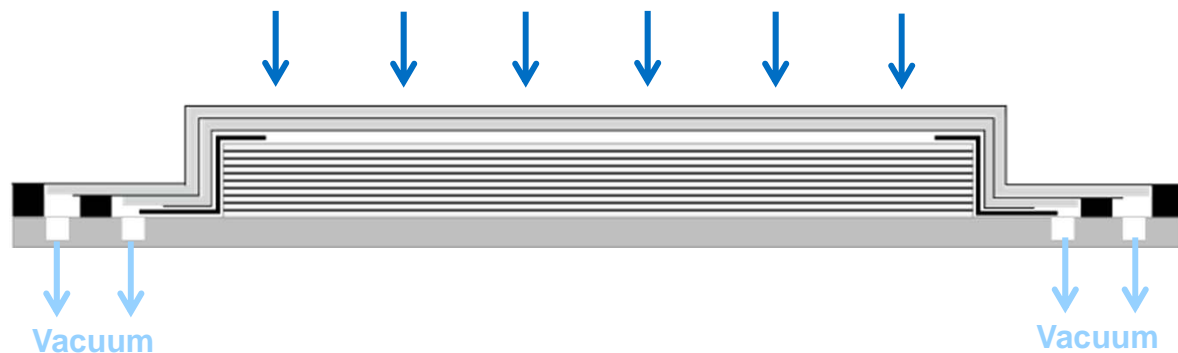
Entrapped air and volatiles have to be extracted prior to gelation !!!!

OoA processes

■ OoA prepreg process:

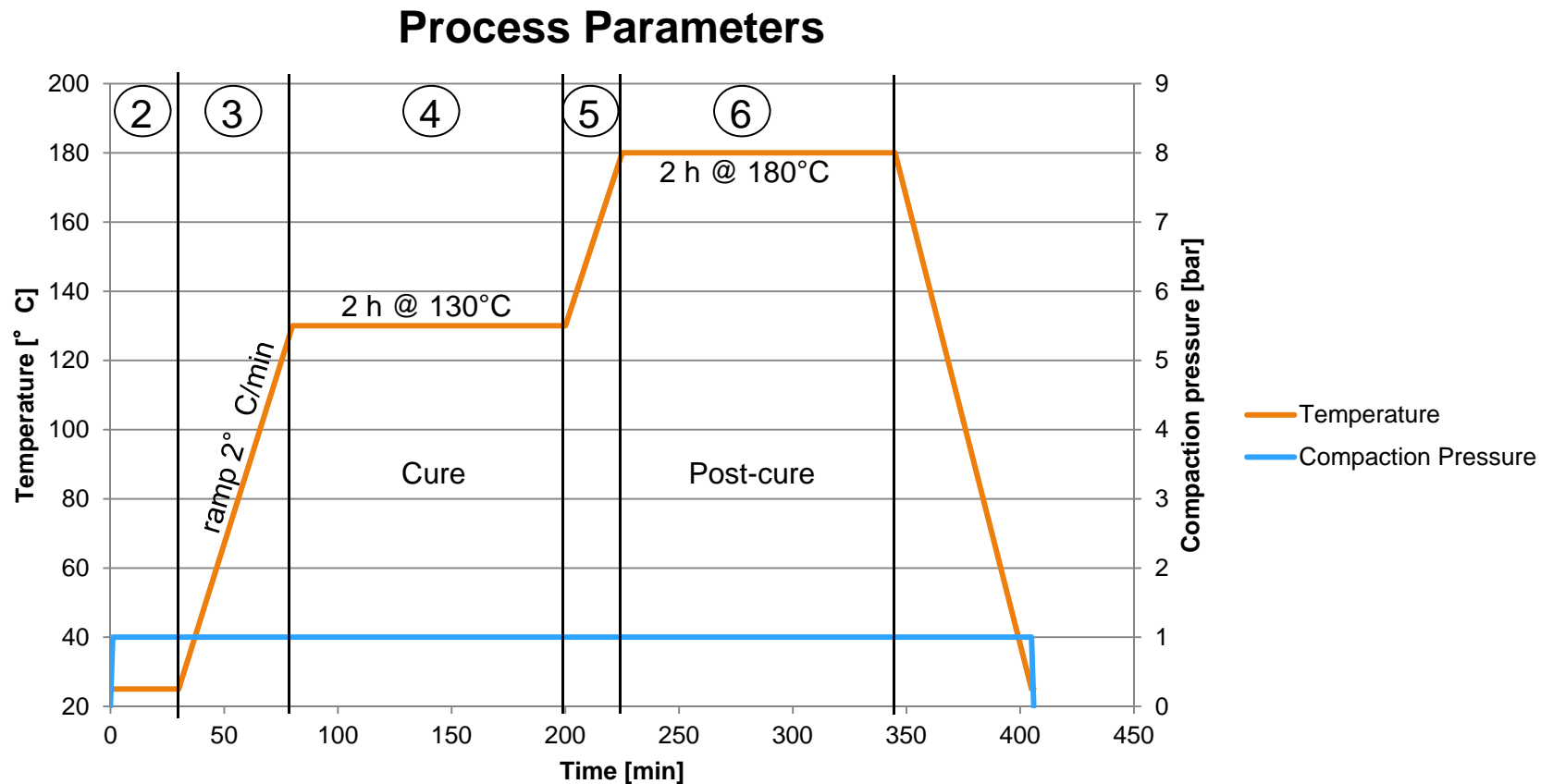
1. Layup, intermediate debulking
2. Debulking
3. Heating to curing temperature
4. Curing process
5. Heating to post-cure temperature
6. Post-cure process

-> Typical post-cure temperature around 180°C



Entrapped air and volatiles have to be extracted prior to gelation !!!!

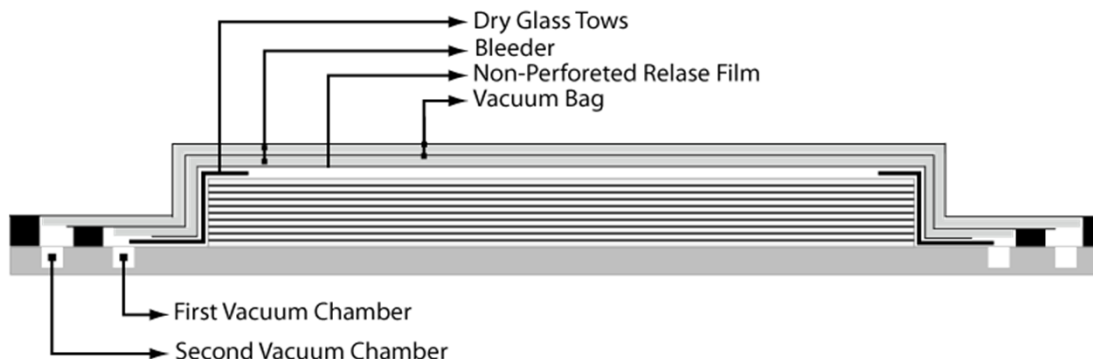
Typical process parameters for VB processing



Generally OoA prepregs are cured at lower temperature than normal autoclave prepregs.

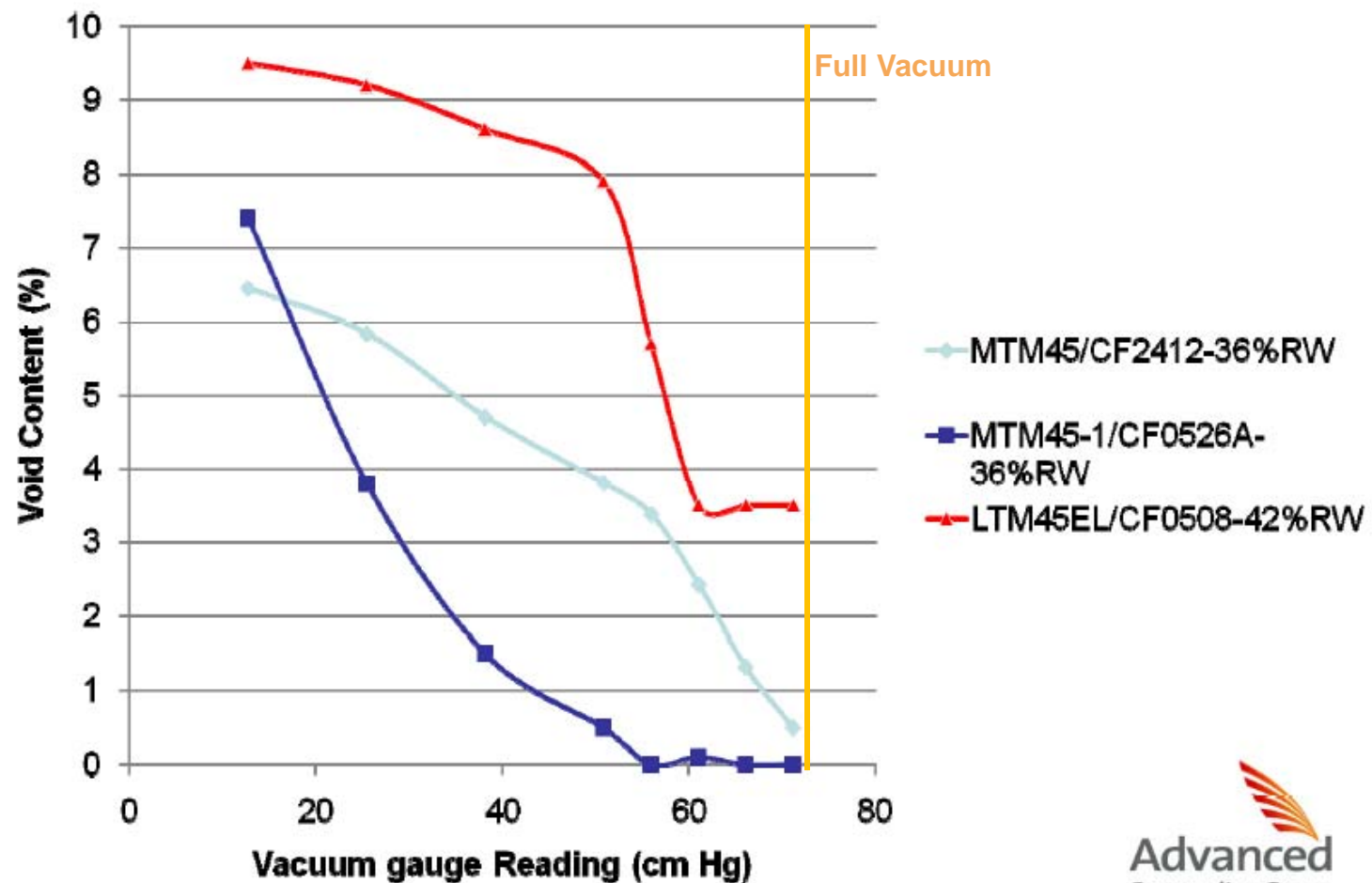
VB arrangement in OoA processes

- Layup, bagging techniques and ancillary material are essentially the same as those used for autoclave curing.
- However:
 - The quality of vacuum become a key process parameters in oven/vacuum cured parts.
A vacuum leak check should be performed prior to cure and heat-up. The test should not show more than 0.068 bar vacuum loss in 10 minutes.
 - Edges breathing have to be improved through accruements



Typical VB
arrangement for
OoA curing with
double vacuum
bag technique.

Laminate Quality vs Vacuum Gauge Reading - LTM45EL, MTM45 and MTM45-1 Fabric Laminates



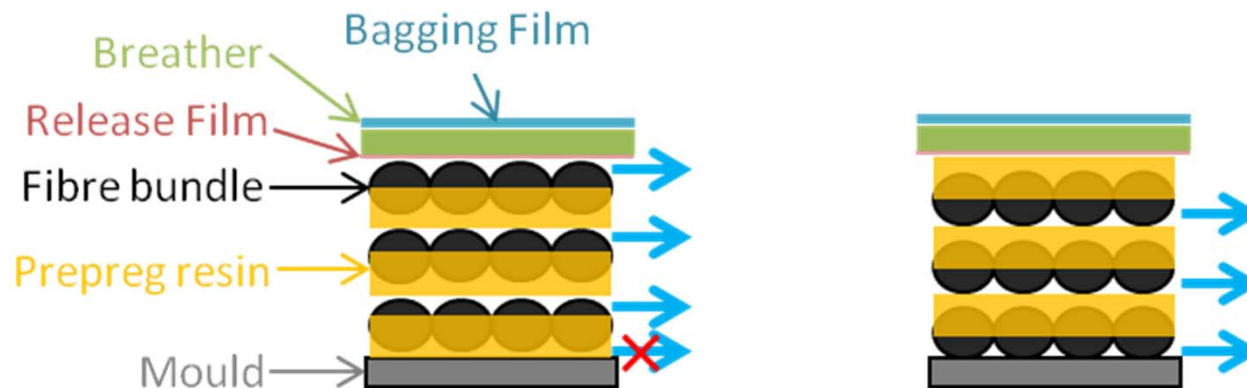
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Chris Ridgard - May 2009

Source: SAMPE Seattle OOA tutorial. Chris Ridgard, 2010

Laminating

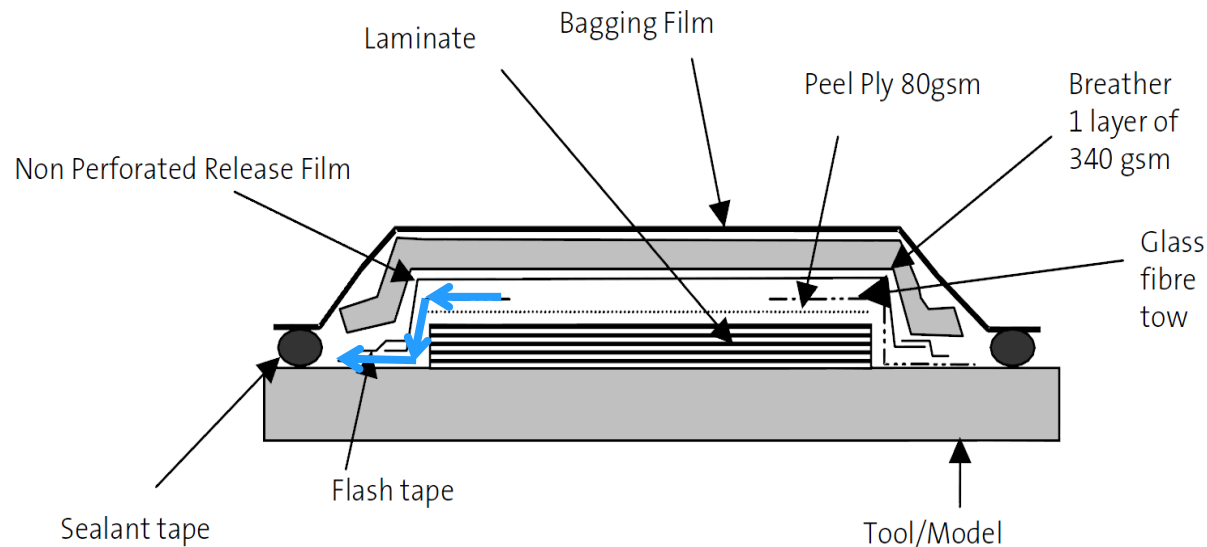
- Most carbon fiber reinforced preregs for hand layup have some degree of dry fiber paths to permit air and volatile extraction during an OOA cure. Degree of impregnation is less than 100%.
- Improved laminate surface quality is achieved when the prepreg is laminated with the drier side towards the mould.



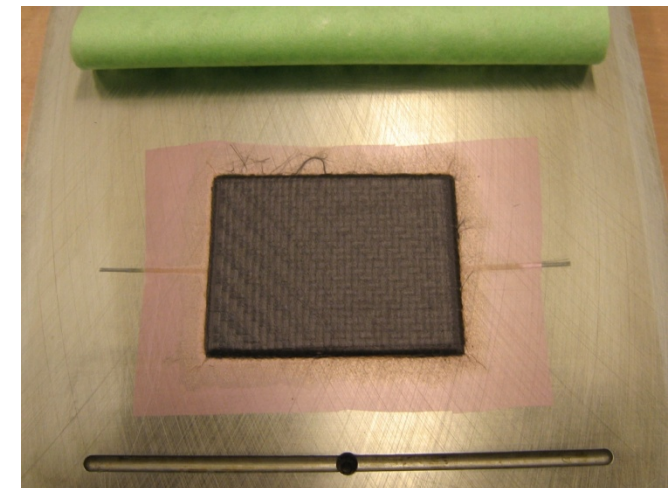
Place the drier side towards the mould permits a better evacuation at the laminate surface.

Overview on different VB techniques

1. Non perforated release film and edge breathing via glass (most common)



Recommended bagging arrangement
for processing MTM®44-1.

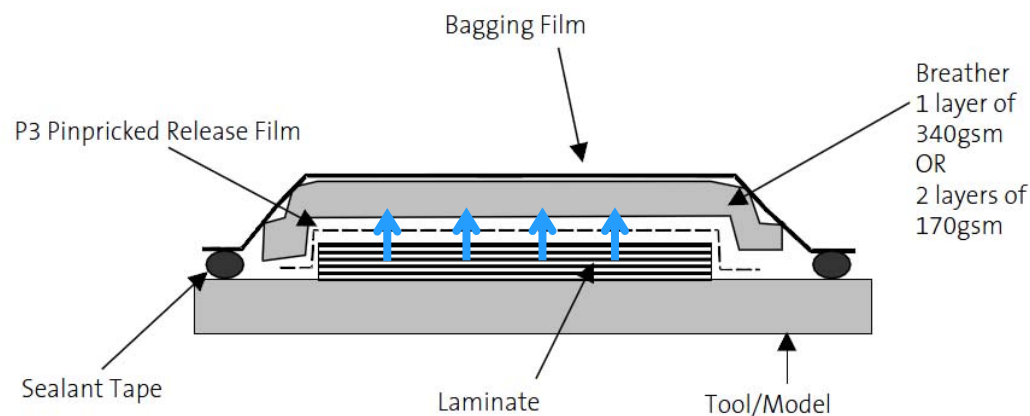


Example of layup on a OoA prepreg plate.
Note: The glass fiber strings must extend beyond the
non-perforated release film and be in contact with the
bleeder.

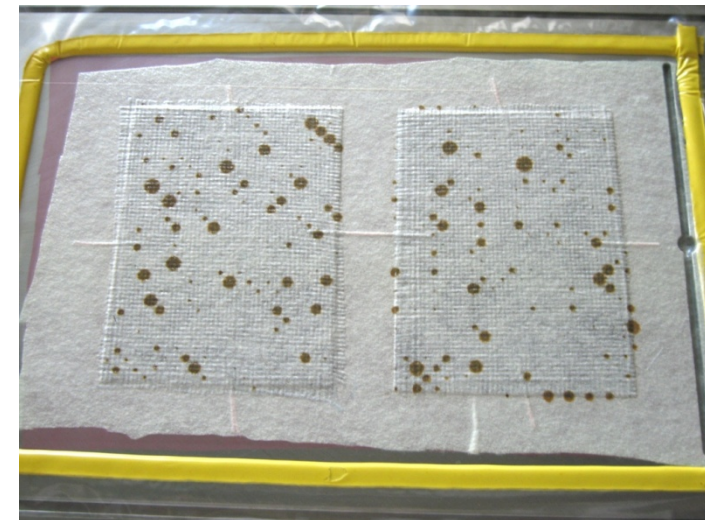
Source: ACG, Users' manual for LTM prepreps.

Overview on different VB techniques

2. Z direction breathing using perforated release film (Arrangement especially used for debulking)



Recommended bagging arrangement for processing some prepreg systems.



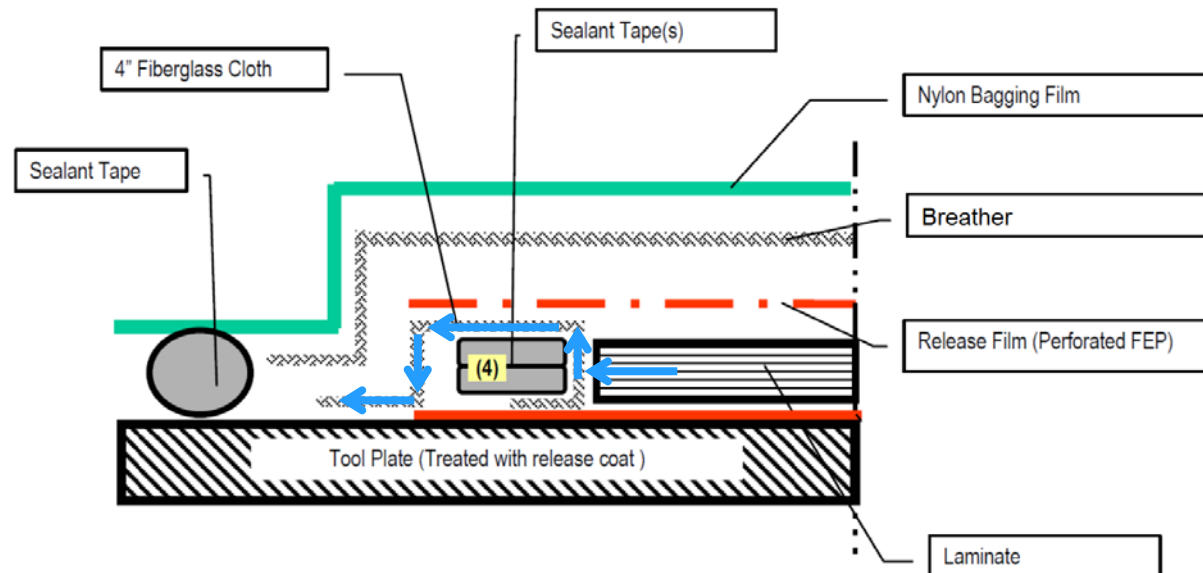
Example of bleeding of the prepreg resin in a VB process

This method should be used only with appropriate prepreg systems, with sufficient excess of resin, in order to compensate the lost into the bleeder.

Source: ACG, Users' manual for LTM prepreps.

Overview on different VB techniques

3. Sealant tape and fiberglass cloth to connect the edges of the laminate with the breather



Vacuum bag arrangement recommended from Cytec for oven cure

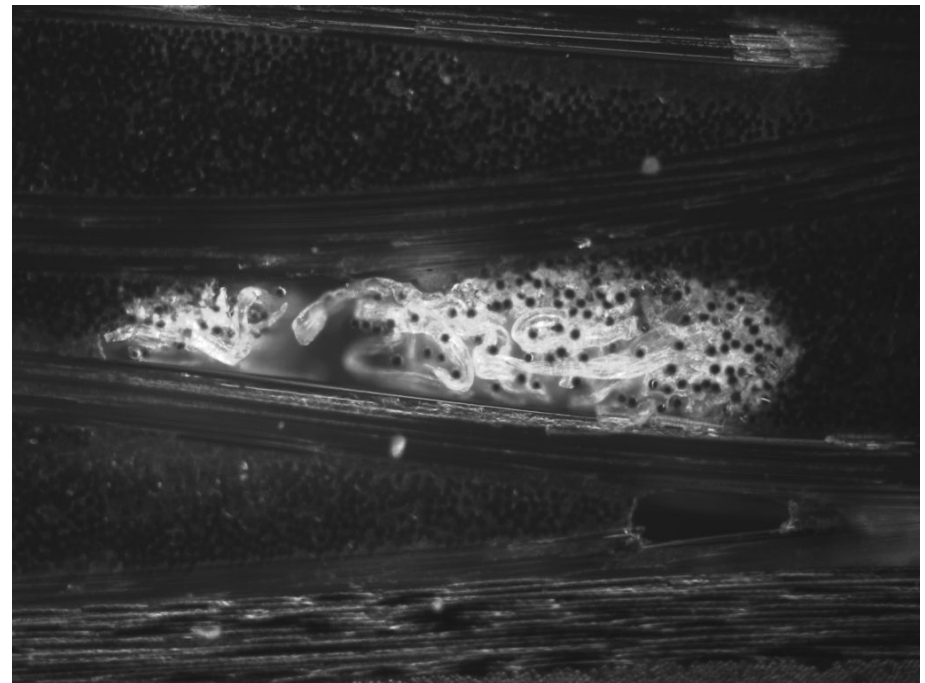
Note: the edge dams need to be higher than the laminate thickness.

Source: Cytec, Cycom 5320-1 epoxy resin system.

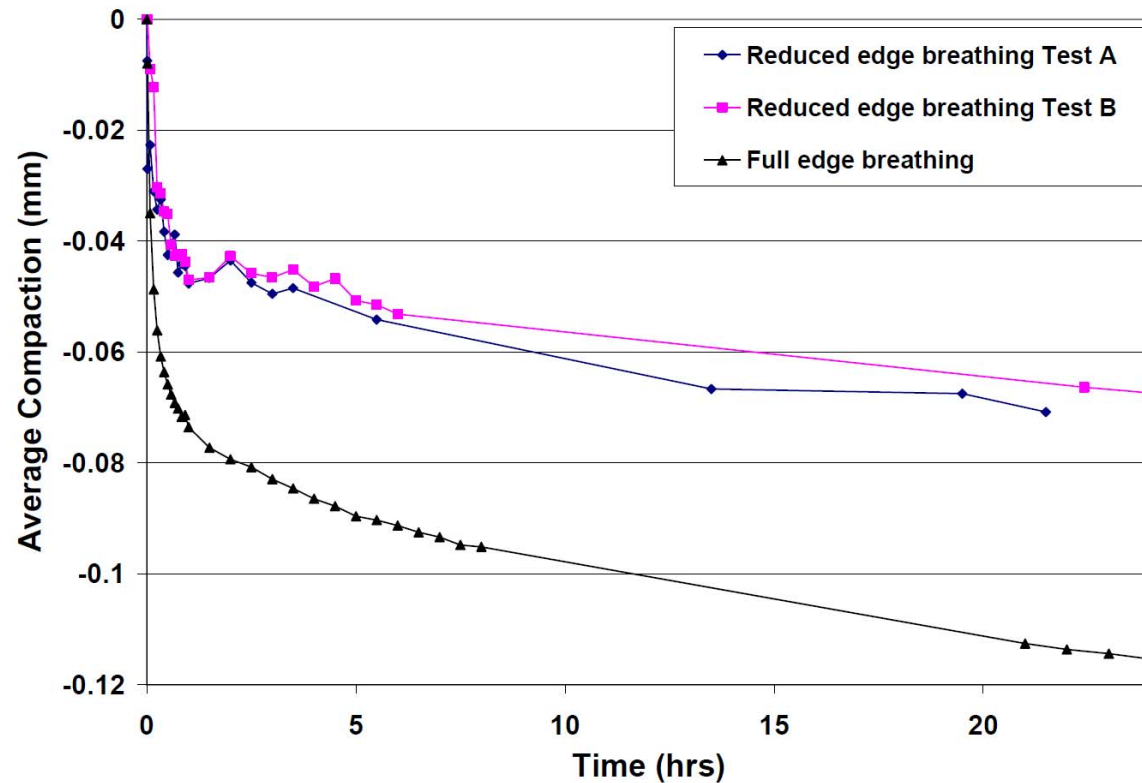
Edge breathing in OOA prepreg processes

- Path tracks created by entrapped air in the laminate

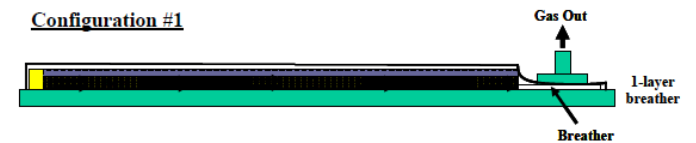
By restricting the evacuation of the air sealing the edges of the laminate with silicon, a large amount of air remain entrapped in the laminate and create path tracks as those show in the microscopes below.



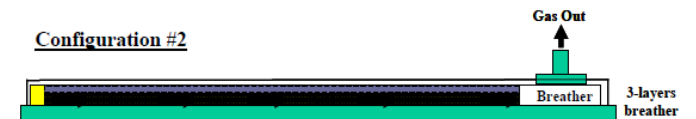
Edge breathing in OOA prepreg processes



Configuration #1



Configuration #2



Source: Gas transport in out-of-autoclave prepreg laminates, B.Louis, 2007.