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Automated composites manufacturing and 4D printing of composites

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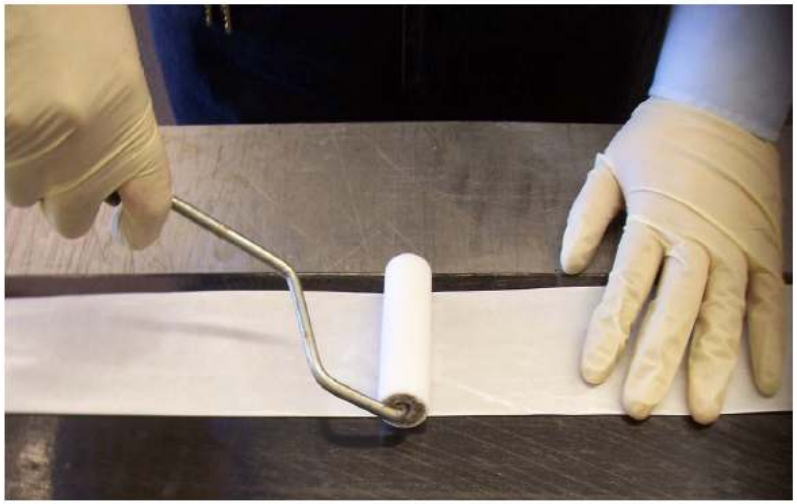
Outline of presentation

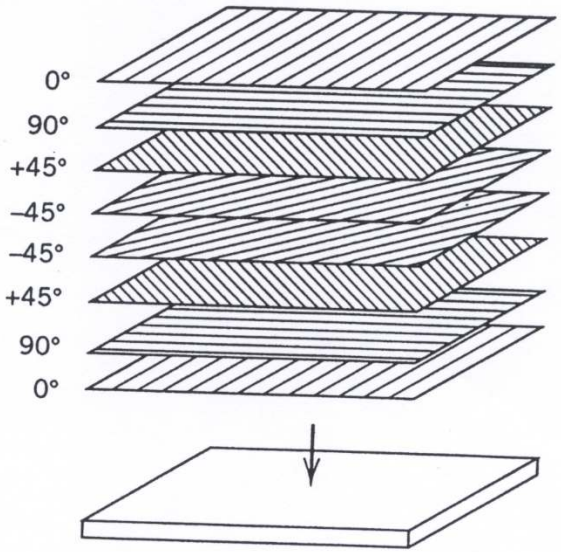
1. Automated Composites Manufacturing and Sustainability in Aviation.
2. Traditional method of composites manufacturing
3. Need for automation of composites manufacturing
4. Advent of automated composites manufacturing: ATL and AFP
4. Advantages of automated composites manufacturing
5. Issues and challenges
6. Unique structures –Unique properties
7. 4D printing of composites
8. Conclusion

Automated Composite Manufacturing (ACM) and Sustainability in Aviation

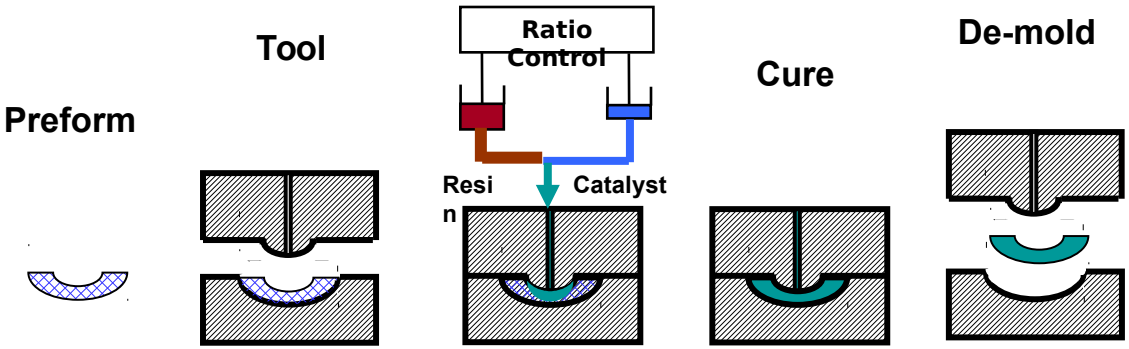
1. Composites offer light weight.
2. ACM reduces waste.
3. ACM speeds up the rate of production
4. ACM reduces variability.
5. Provides opportunities to develop thermoplastic composite structures- No shelf life- Recyclability.
6. Facilitates the manufacturing of large composite structures.
7. Fiber steering- Optimal use of materials.
8. Enable 4D printing (moldless manufacturing)

Traditional method of composites manufacturing



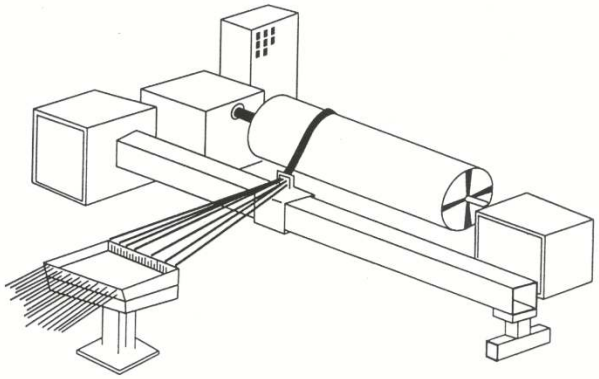


Hand Lay Up



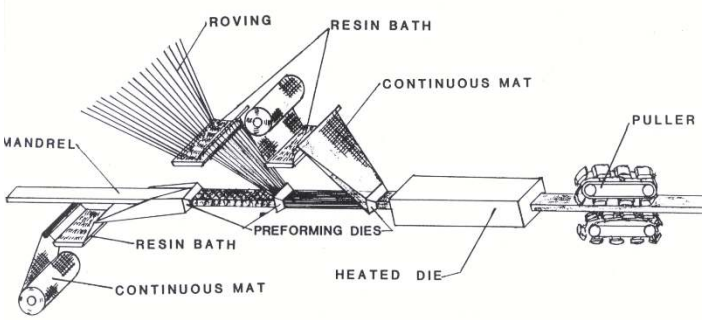
Liquid Composite molding (LCM)

Traditional method of composites manufacturing

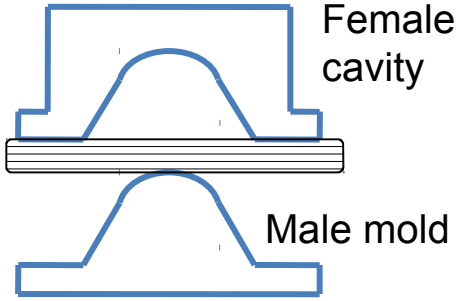


Filament winding

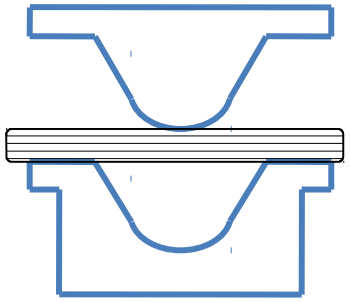
Pultrusion



Compression molding



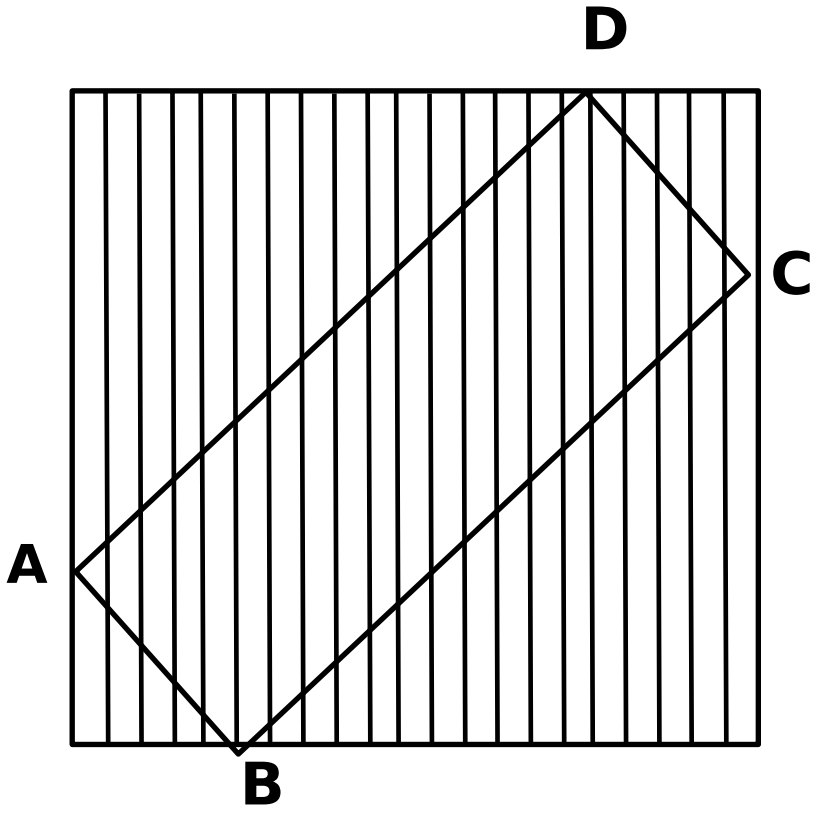
Male mold - bottom



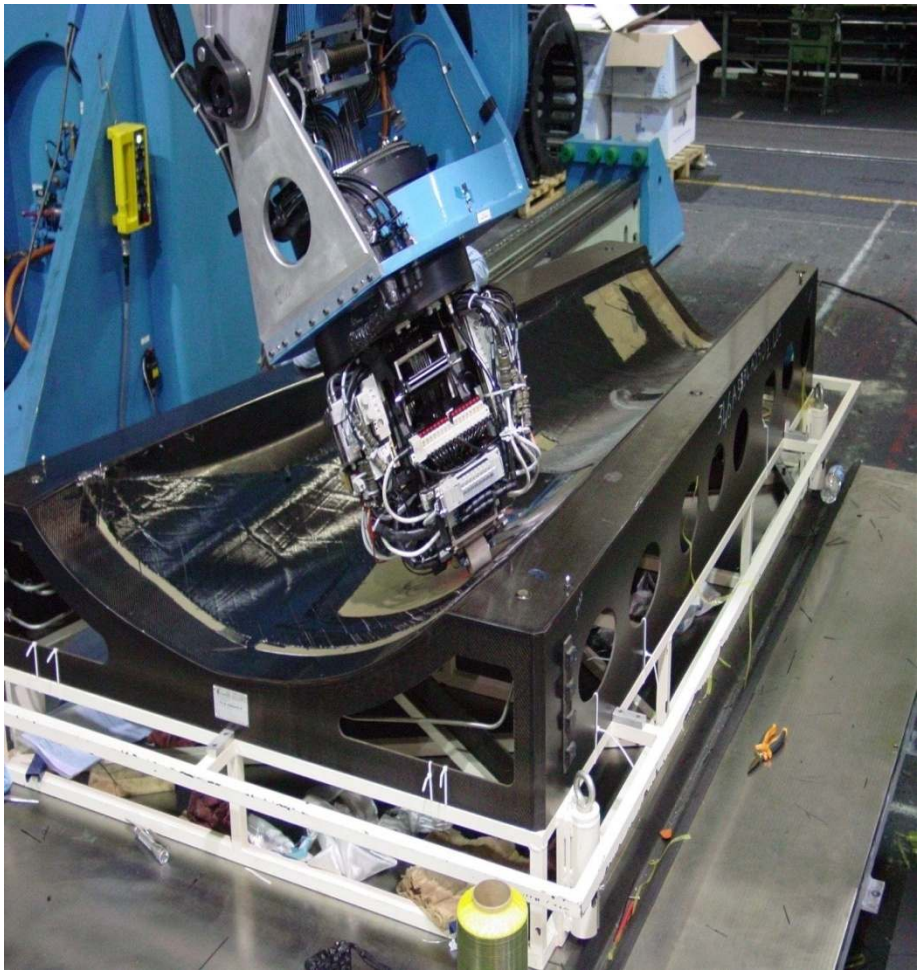
Female mold- bottom

Need for automation in the manufacturing of composites

1. HLU rate of material deposition is slow (2.2 lbs/hr). Fuselage of 5 m diameter, 15 m long, 3 mm thick would take 1 worker 1272 hours to lay down.
2. Manual lay up is not practical to lay materials on large structures.
3. Issues with repeatability. Consistency of quality.
4. Material waste. Buy/Fly ratio = 3



Industrial machines (mainly focused on high speed of material deposition)



Ingersoll machines

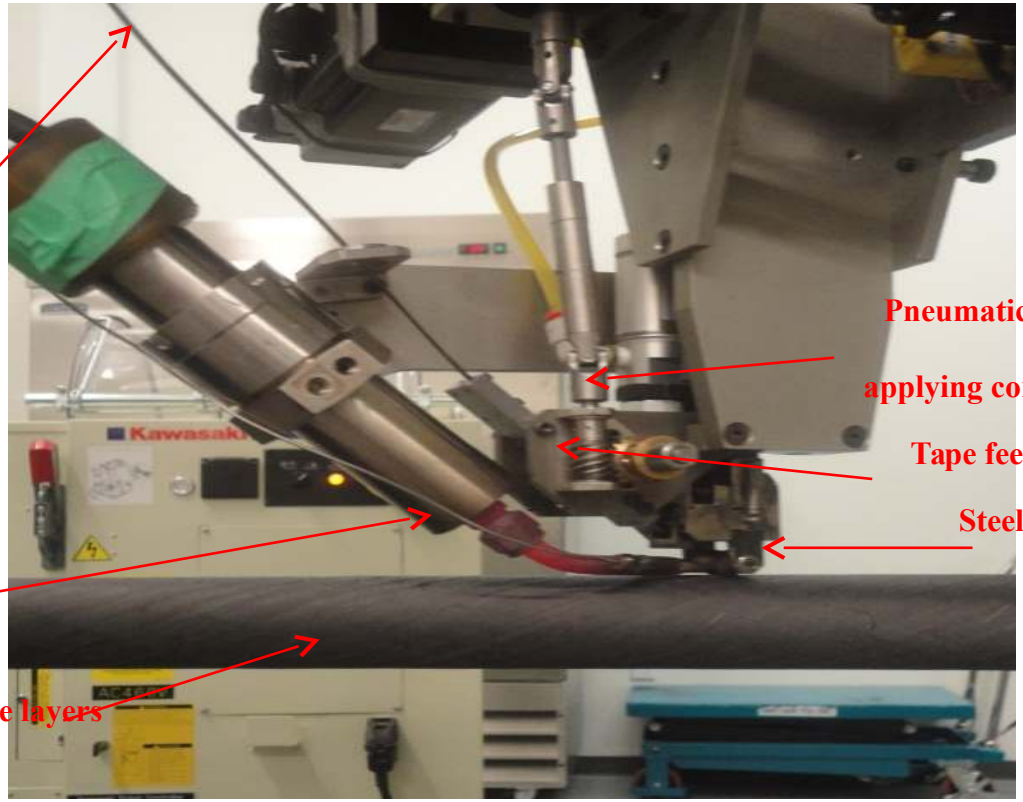
Automated Tape Lay Up (ATL) and Automated Fiber Placement (AFP) machines

Automated Tape Lay Up (ATL) machine

1. Mainly for thermoset lay up
2. Lay down wide tapes (tape width up to 12 inch)
3. Fast lay up

Automated Fiber Placement (AFP)

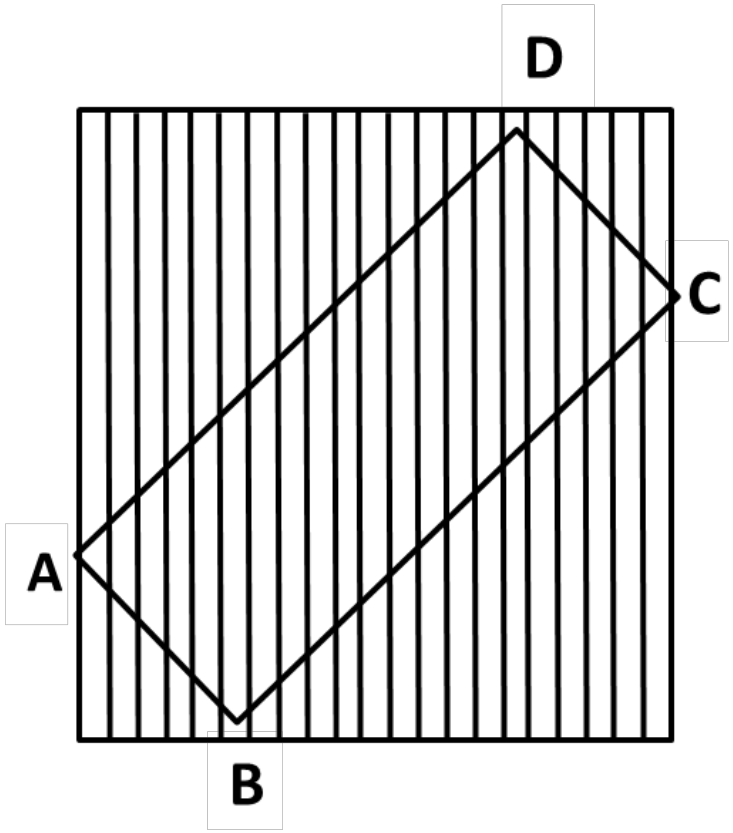
1. Thermoset and thermoplastic composites
2. Can lay down one tow or multiple tows at once
3. Individual tow cutting capability


Incoming composite tape
Pneumatic cylinder for
applying compaction force
Tape feeder
Steel compaction roller
Nitrogen Hot Gas Torch
Laid down thermoplastic composite layers

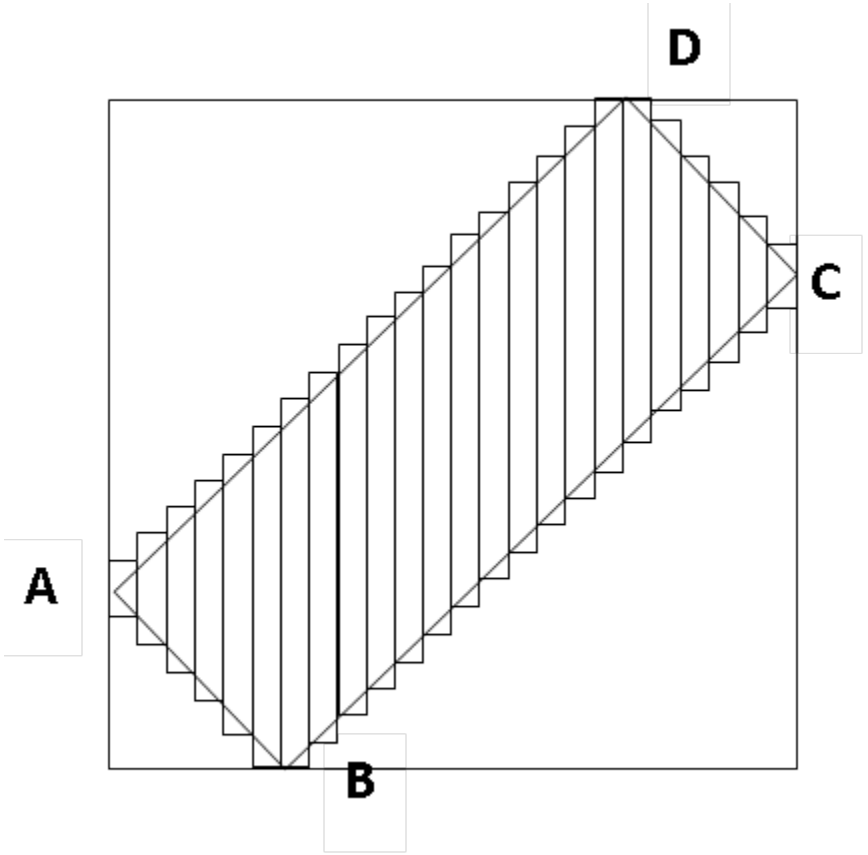
Advantages of automated composites manufacturing

1. Faster rate of material deposition (about 20 lbs/hr compared to 2.2 lbs/hr for HLU).
2. Reduce debulking time
3. Less manual labor intensive
4. Less variability, better repeatability.
5. Essential to handle large structures.
6. Smoother transition between design and manufacturing
7. Less material wastage
8. Ability to steer fibers
9. Capability to make unique structures

Less material wastage



Hand Lay Up

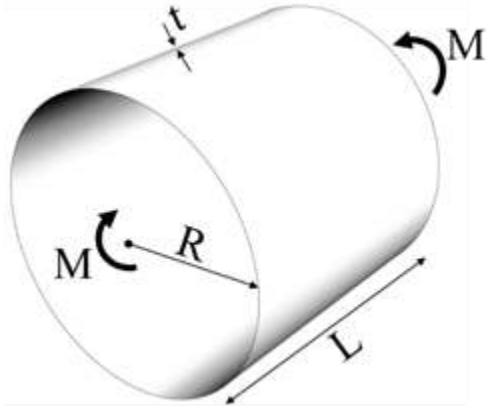


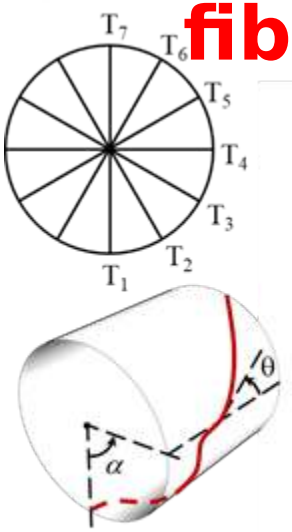
AFP

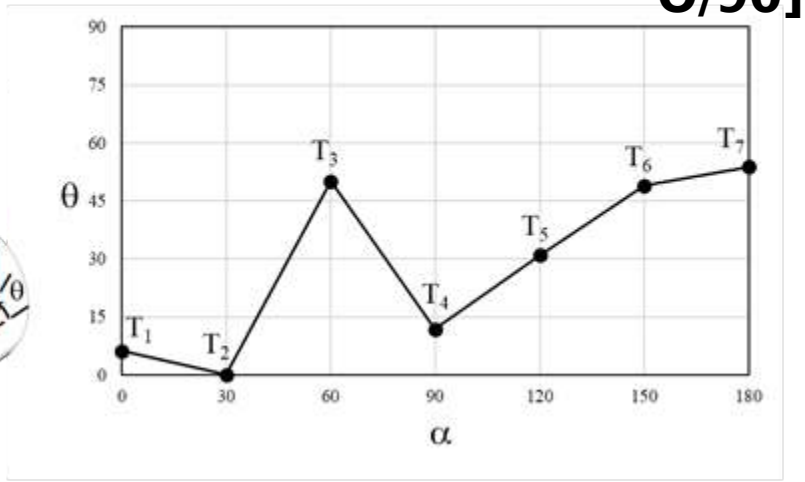
Ability to steer fibers

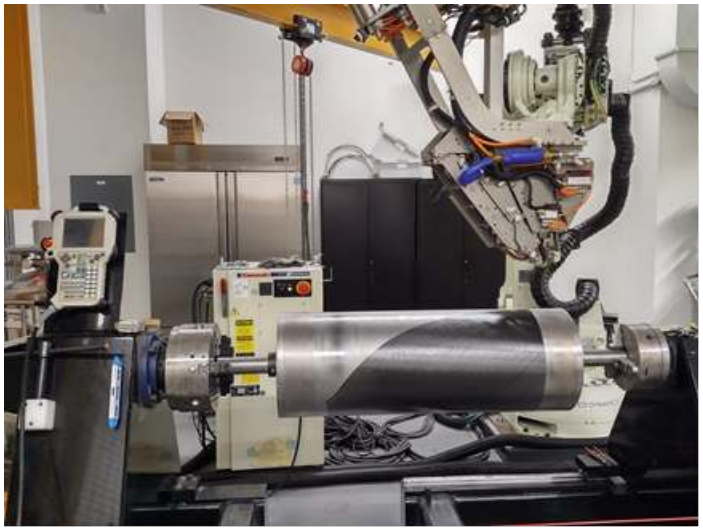
[0/45/-45/90]s

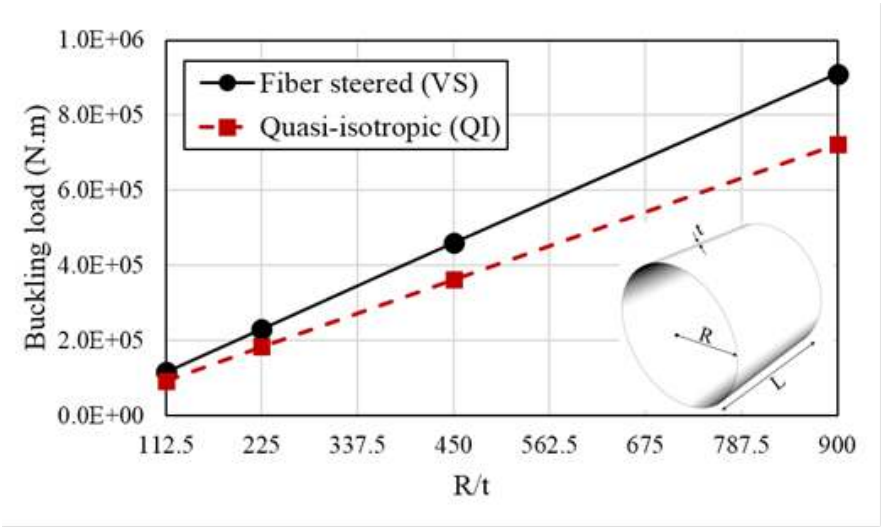
[0/Θ/-Θ/90]s







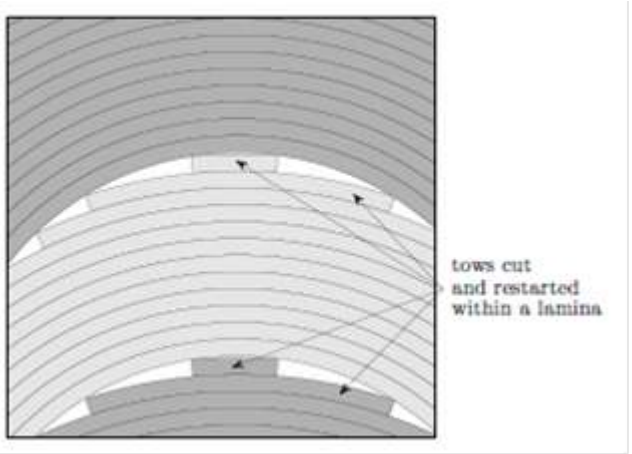


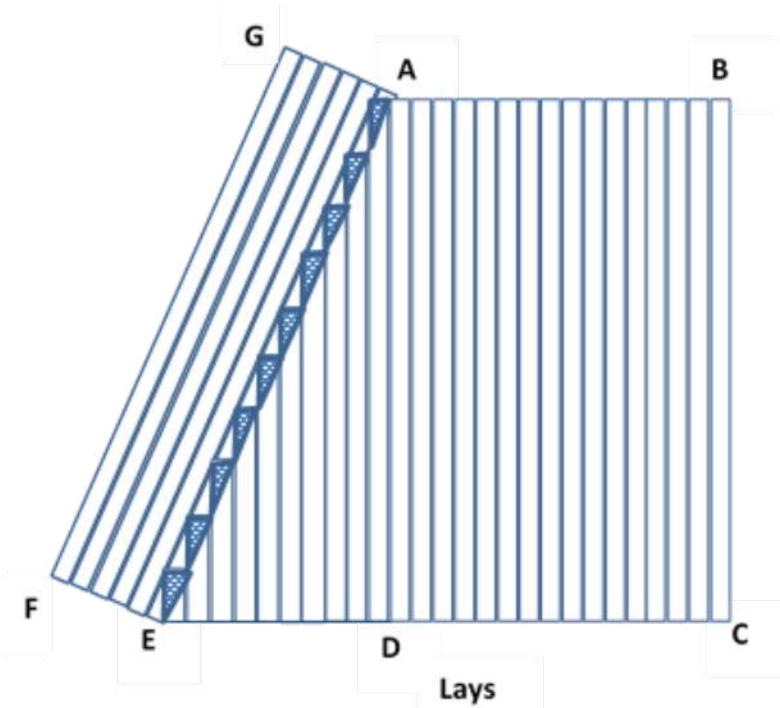


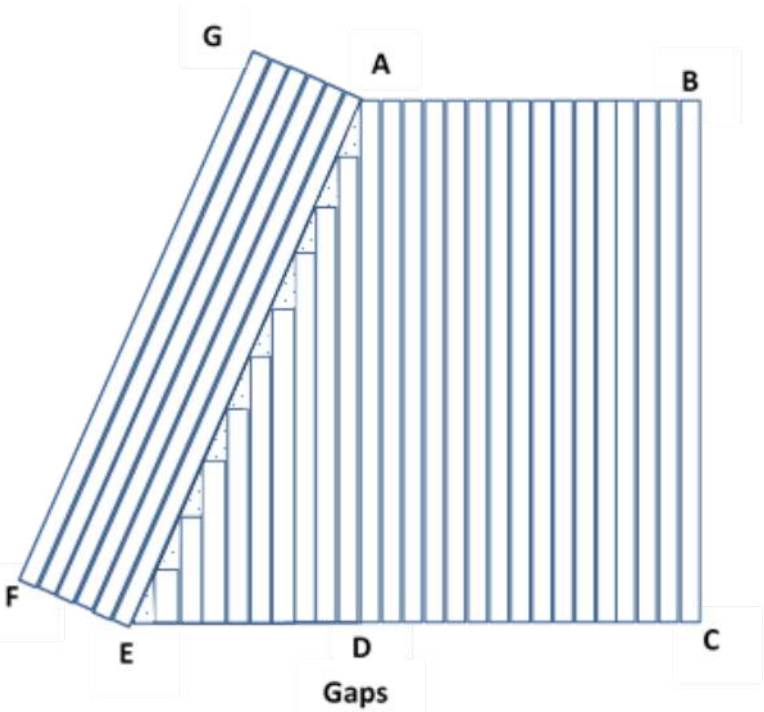
Issues with automated composites manufacturing

1. High machine cost.
2. Steep learning curve
3. Expensive operation.
4. Occurrence of laps and gaps
5. Serrated edges at boundaries
6. Defects due to steering.
7. In-plane waviness.
8. Ability to detect defects in-situ
9. Distortion of components made of thermoplastic composites.

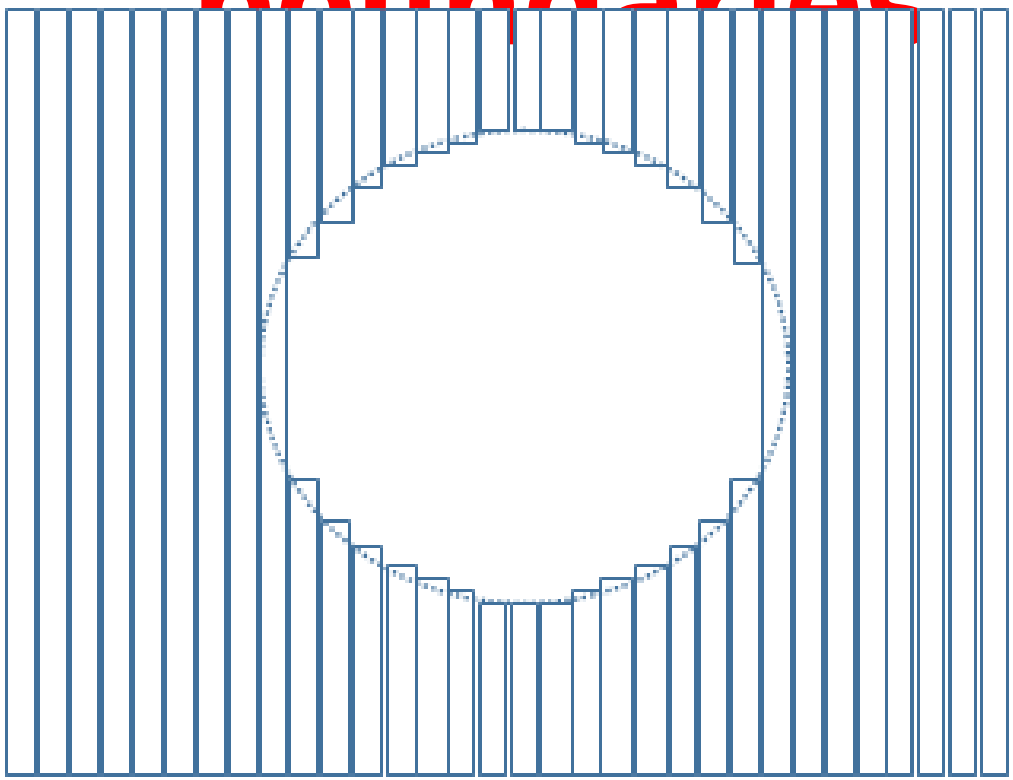
Occurrence of laps and gaps



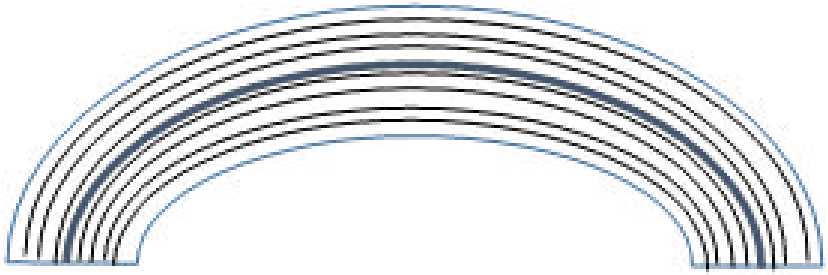




Serrated edges at boundaries



Defects due to fiber steering



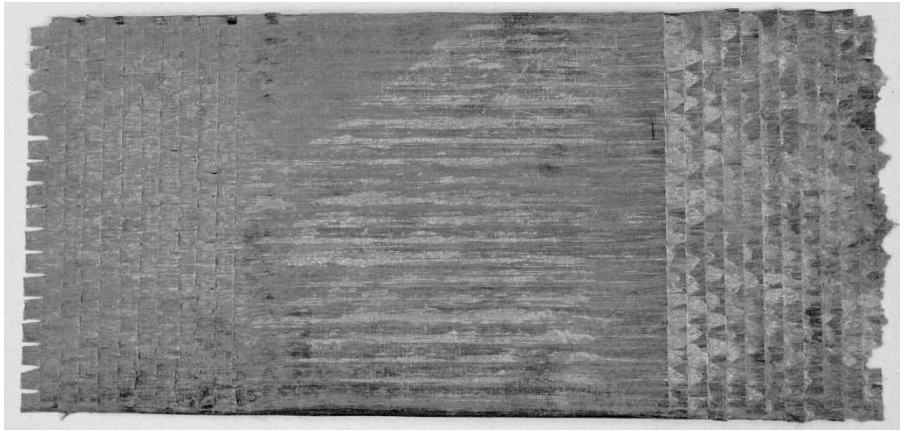
1. Buckling of inner fibers
2. Raised edge-Fish eyes
3. Fold overs
4. Limited radius

In-plane waviness

Distortion of components made of thermoplastic composites

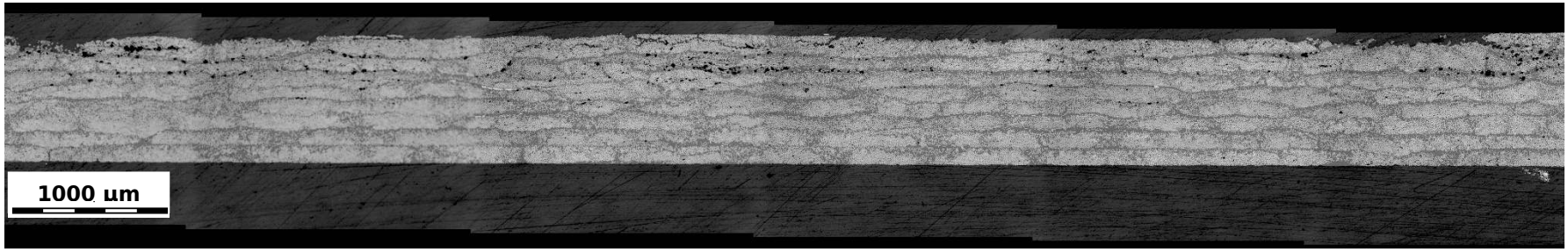
Structures with free edges (plates, shells, panels)
can exhibit distortion- Cold mandrel

Distortion problem can be solved using hot mandrel to make laminates with free edges

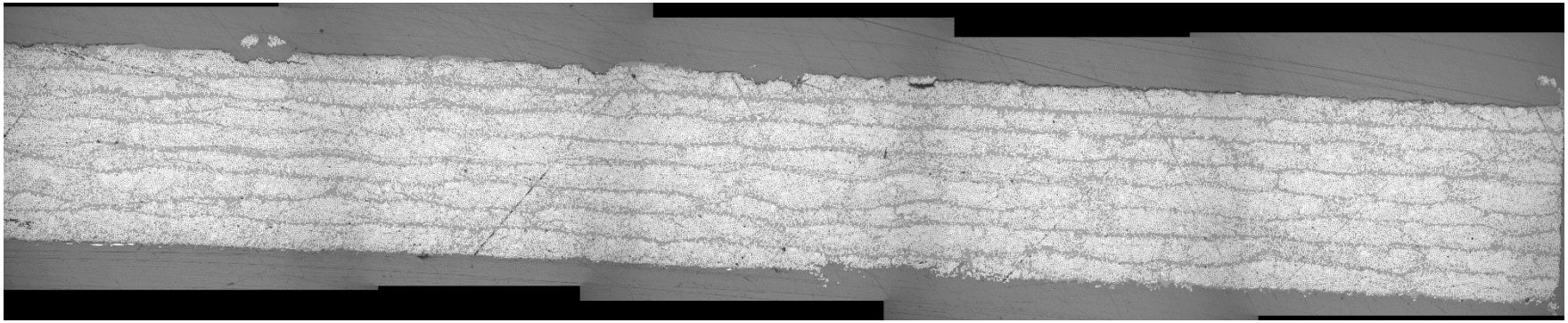


Occurrence of voids in thermoplastic composites

Voids can occur on top layers

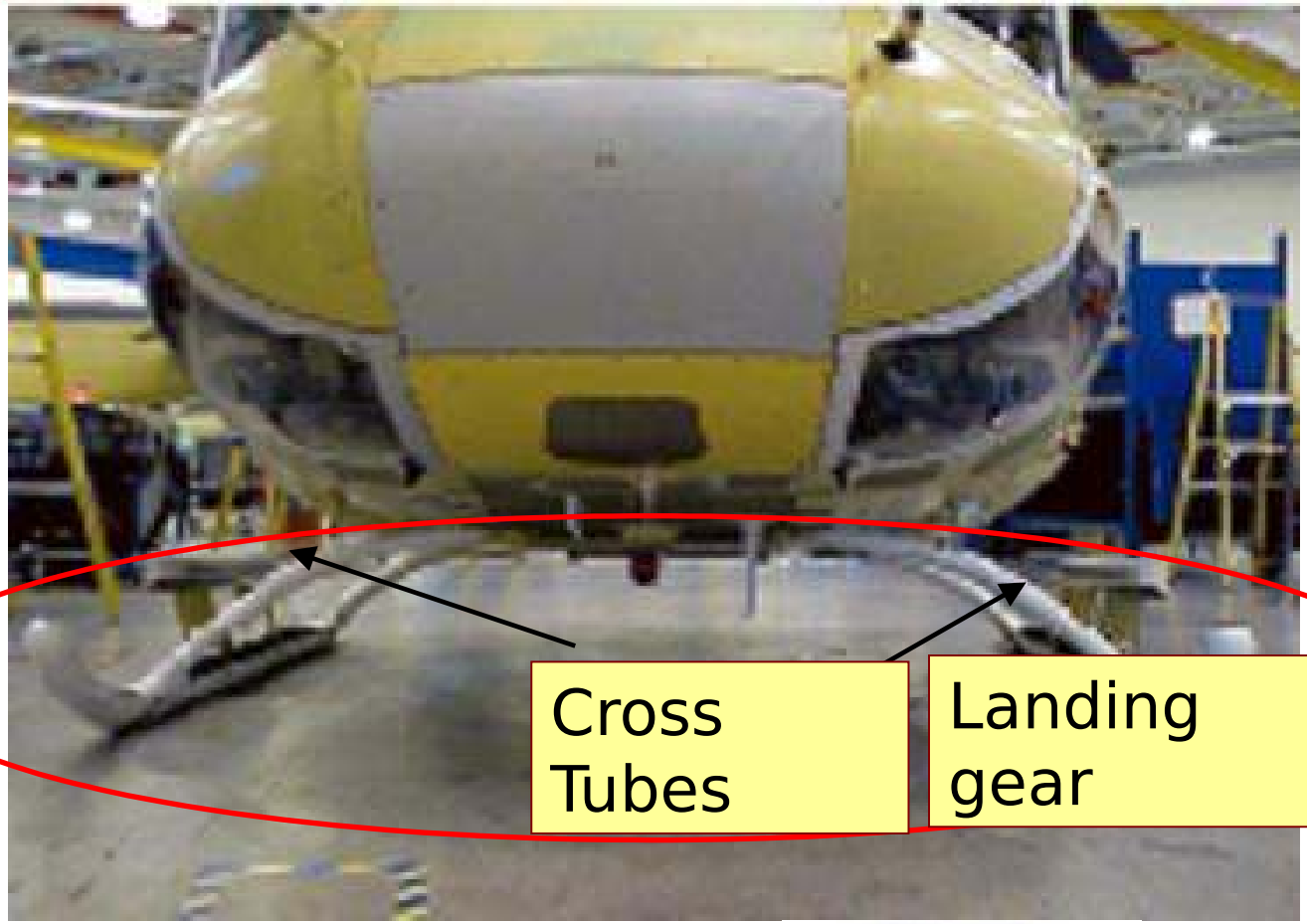


This problem can be resolved by using repasses- This means

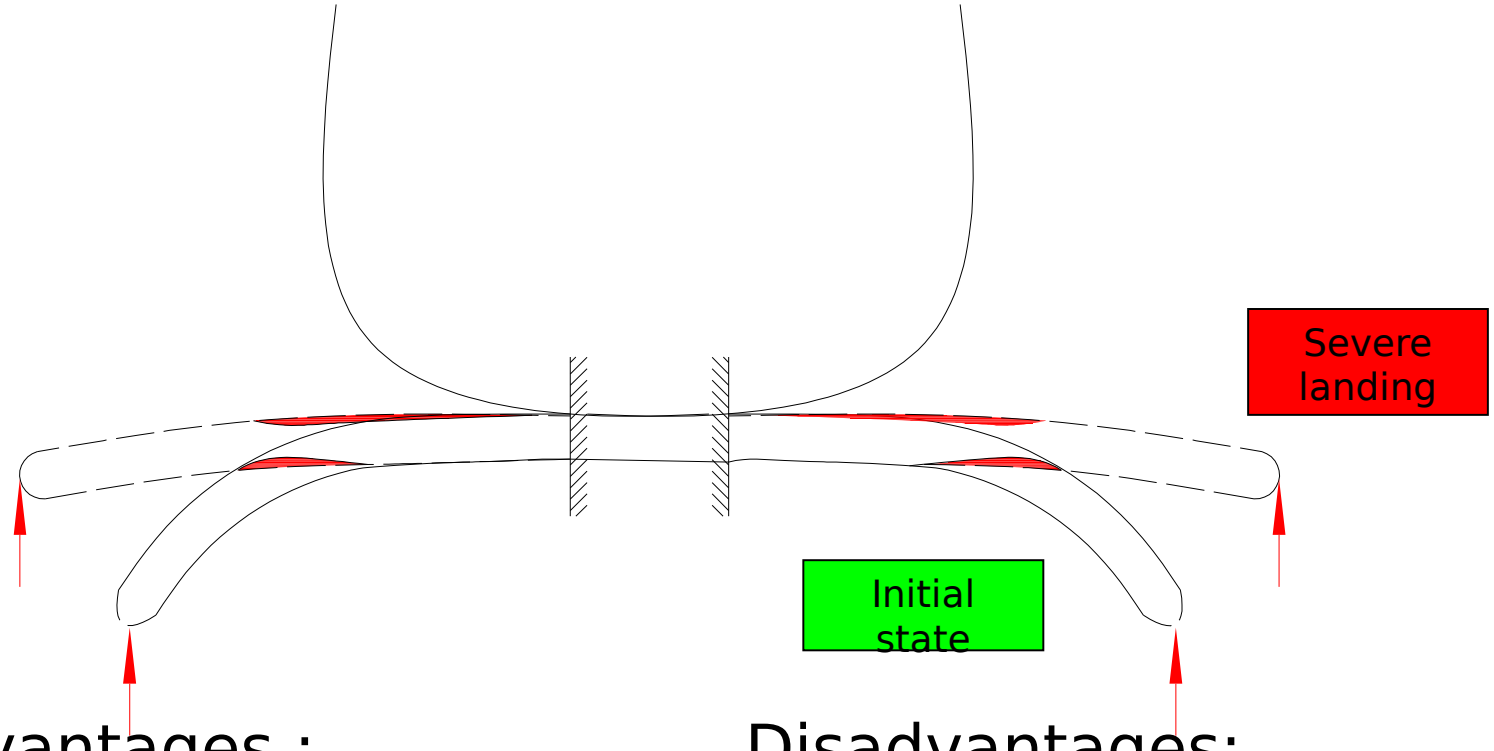


Unique structures- Unique properties

Unique structures



Current design- Aluminum 7075-T6



Advantages :

- Very ductile
- No abrupt fracture

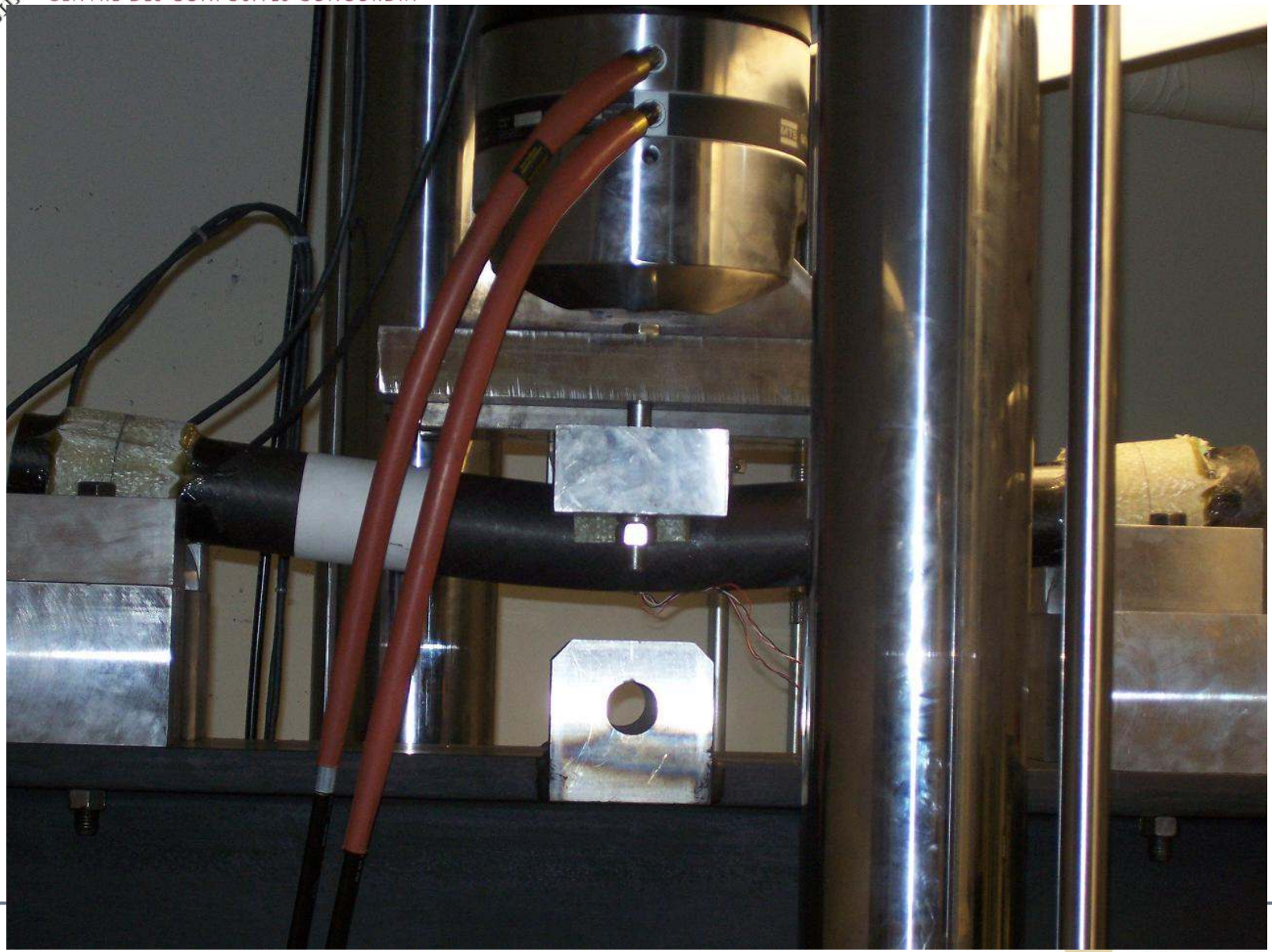
Disadvantages:

- Fabrication process
- Spot Corrosion
- Cost

Challenges

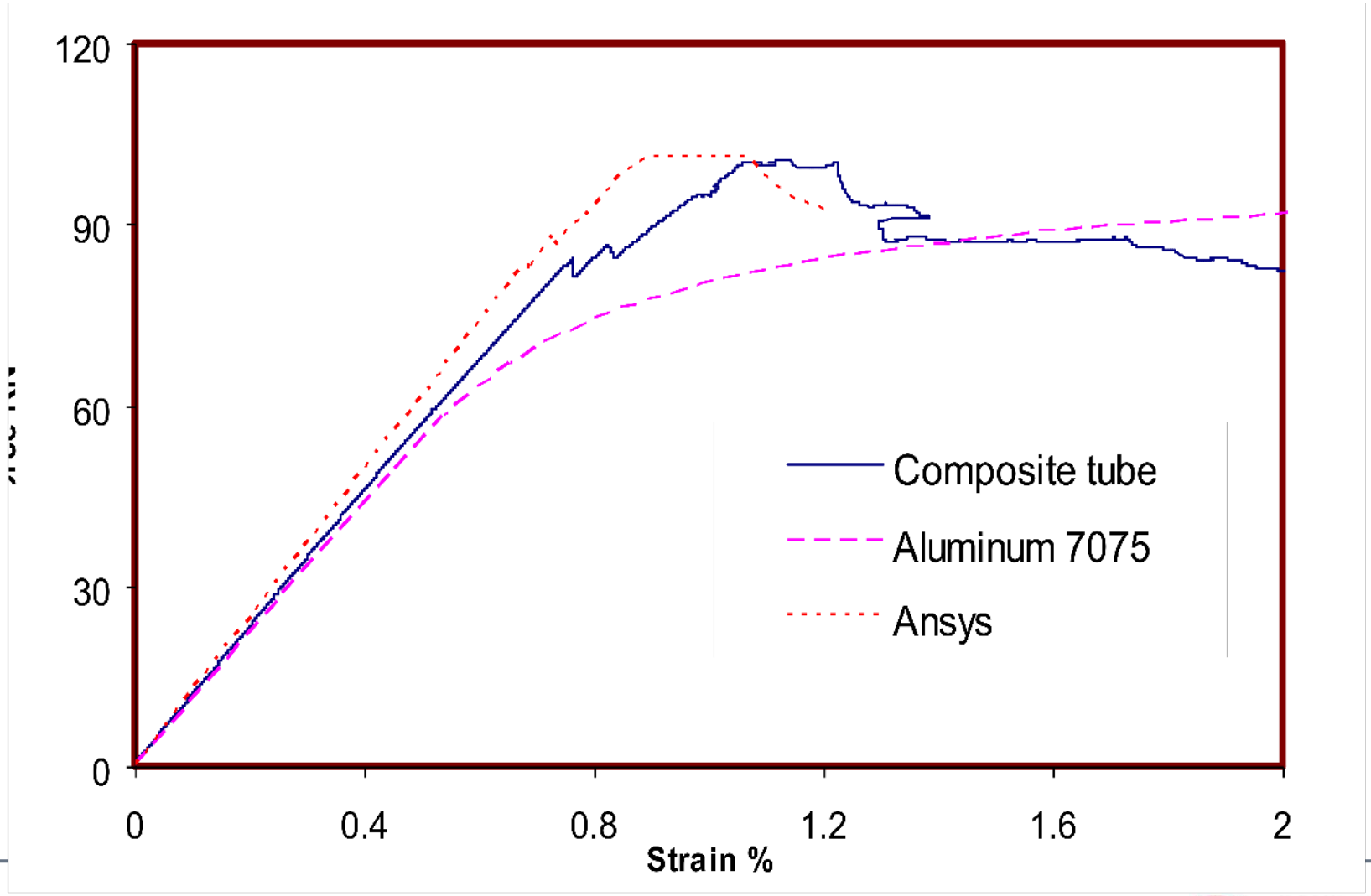
Composites are relatively brittle

Unique structures



Three Point Bending test; 4th composite tube

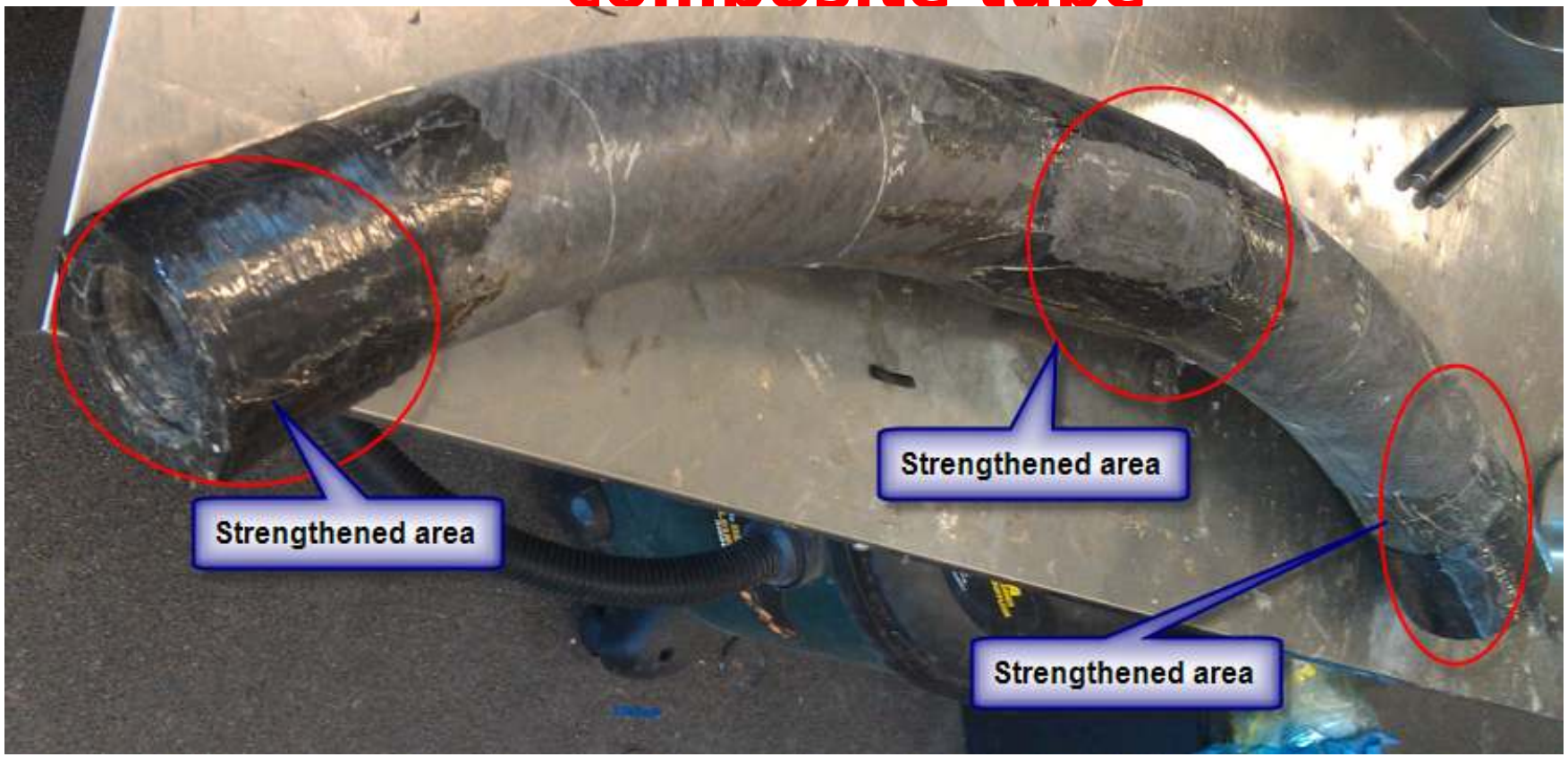
ID 56mm, OD 78 mm



Composite tube is 30% lighter than aluminum tube-

Curved tube

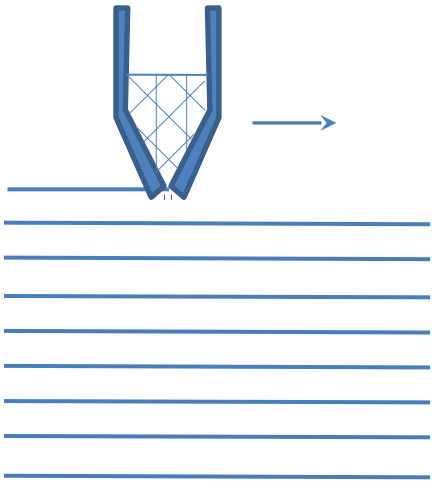
Curved thermoplastic composite tube



4D printing of composites

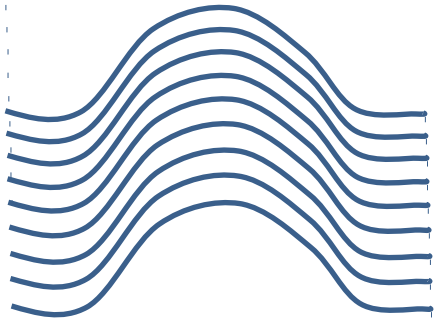
Combination of 3D printing and self re-configuration after material deposition.

Exploits the anisotropy of composite materials



3-D Printing

Activation Process: Heat, electricity, Light, Moisture, magnetic field



Self-Reconfiguration

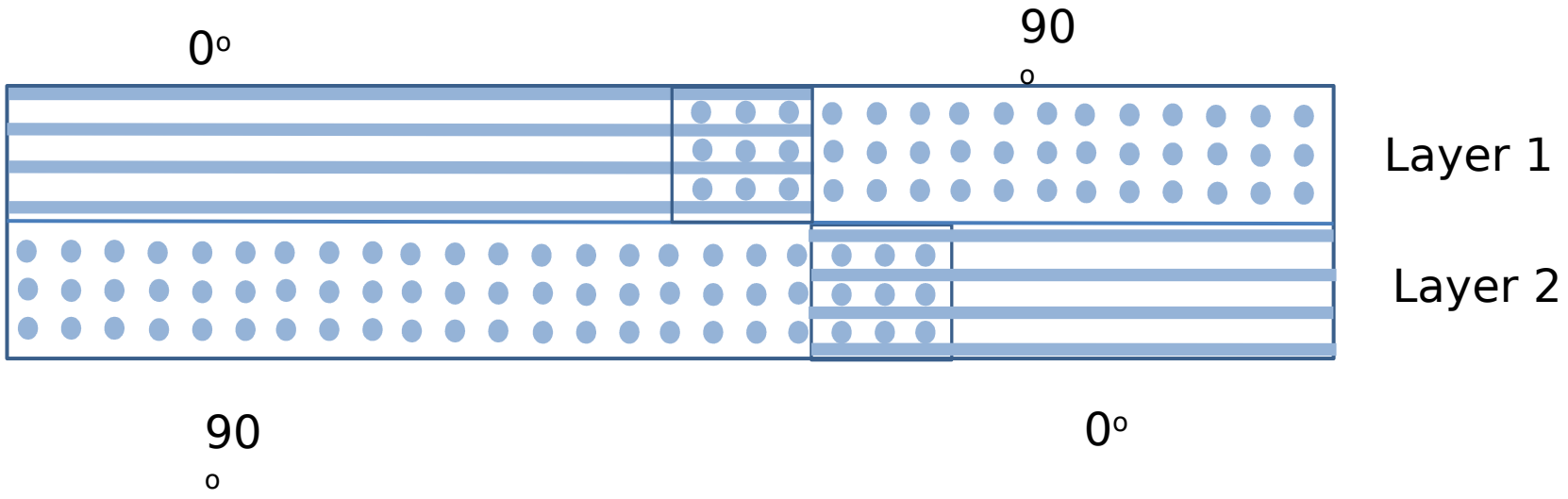
4D printing of composites

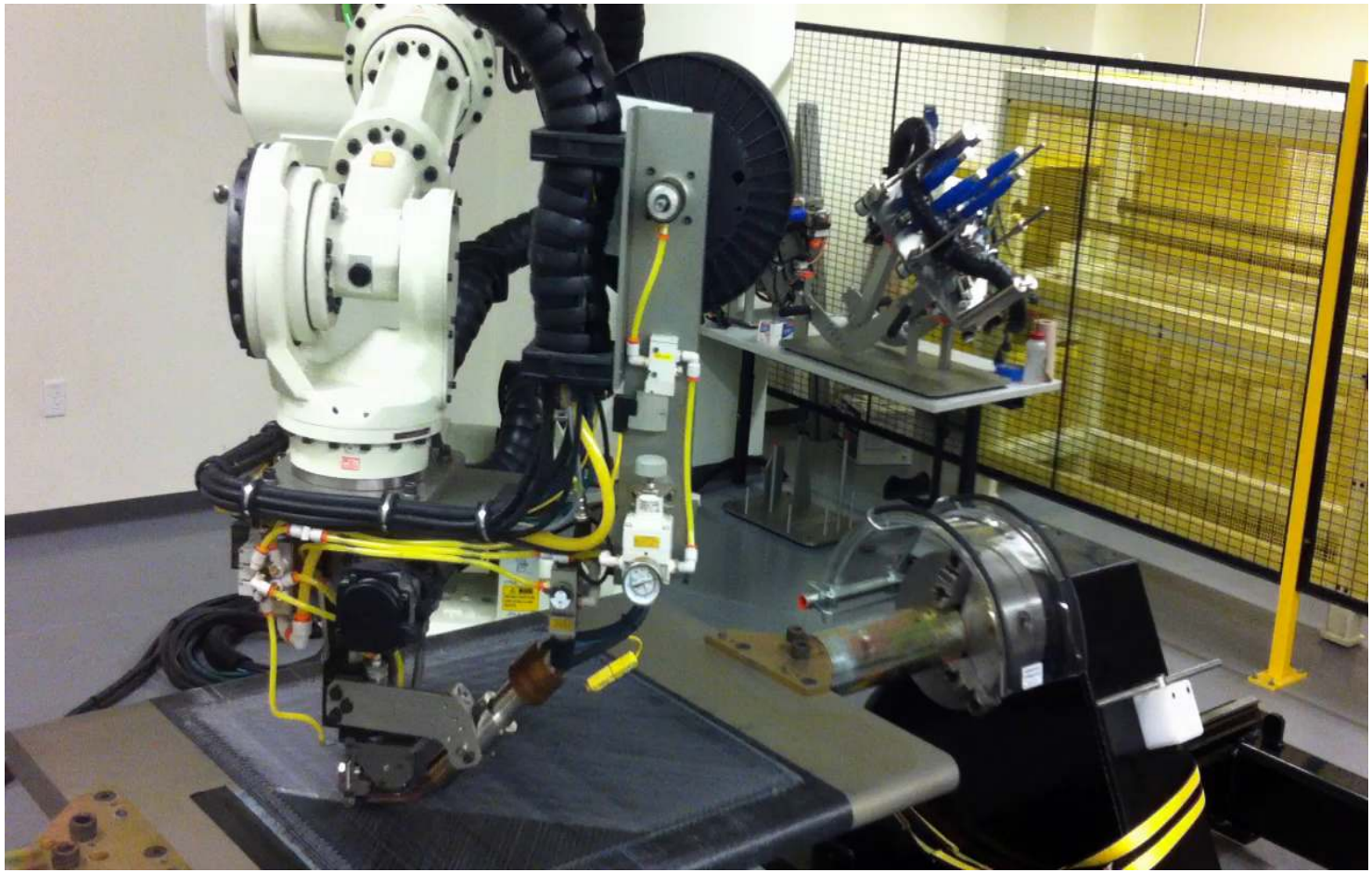
4D printing with composites

1. Automated fiber placement machines can be used to deposit layers additively to produce stacks of composite layers.

2. Anisotropic properties of composite materials may be used to produce deformations upon use of heat activation.

3. Structures of complex geometries and good mechanical properties can be made.


0o
90o
Layer 1
Layer 2
90o
0o



Conclusion

In spite of the many issues that need to be resolved, Automated Composites Manufacturing holds a lot of promise for the manufacturing of composites structures in the future.

Conclusion

By using anisotropic properties of composites, one can make engineering structures that can re-configure into desirable shape after material deposition using additive manufacturing.

Complex structures can be made without using complex molds

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