Introduction to Tooling for Composite Materials Processing

CO-HOSTED BY:

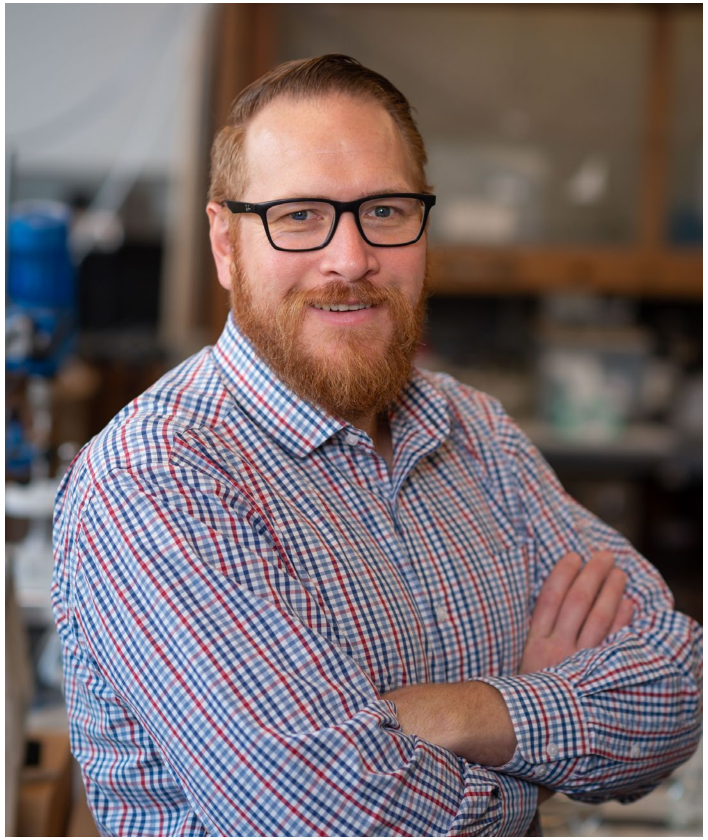
Composites Knowledge Network

sampe Canada

compositeskn.org

nasampe.org

YOUR HOSTS



Casey Keulen, Ph.D, P.Eng.
Assistant Professor of Teaching, University of British Columbia
Director of Advanced Materials Manufacturing MEL Program, UBC
Director of Knowledge in Practice Centre, CKN

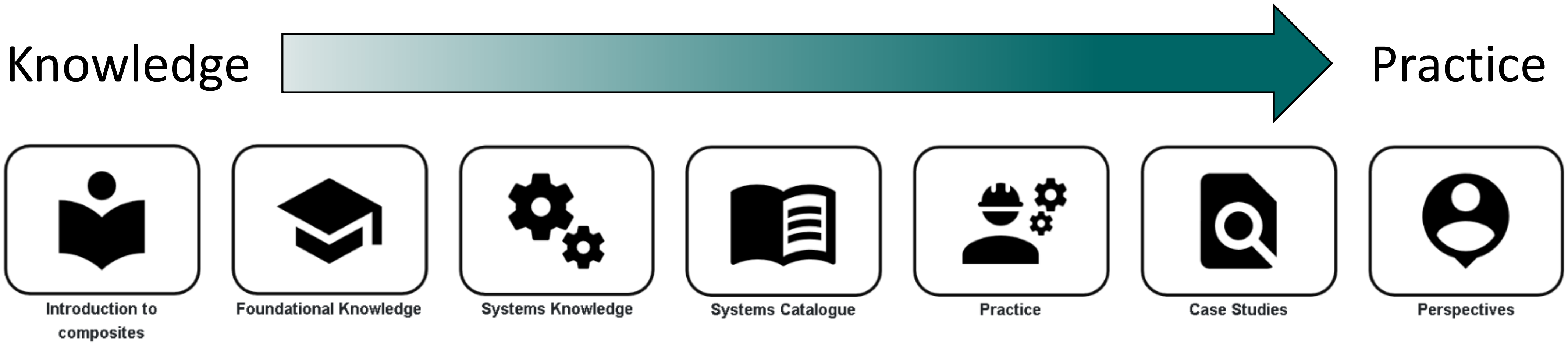
- Ph.D. and M.A.Sc. in Composite Materials Engineering
- Over 15 years experience in industry and academia working on polymer matrix composites in aerospace, automotive, marine, energy, recreation and others
- Experience working with over 150 companies from SME to major international corporations
- Expertise in liquid composite moulding and thermal management

KNOWLEDGE IN PRACTICE CENTRE (KPC)

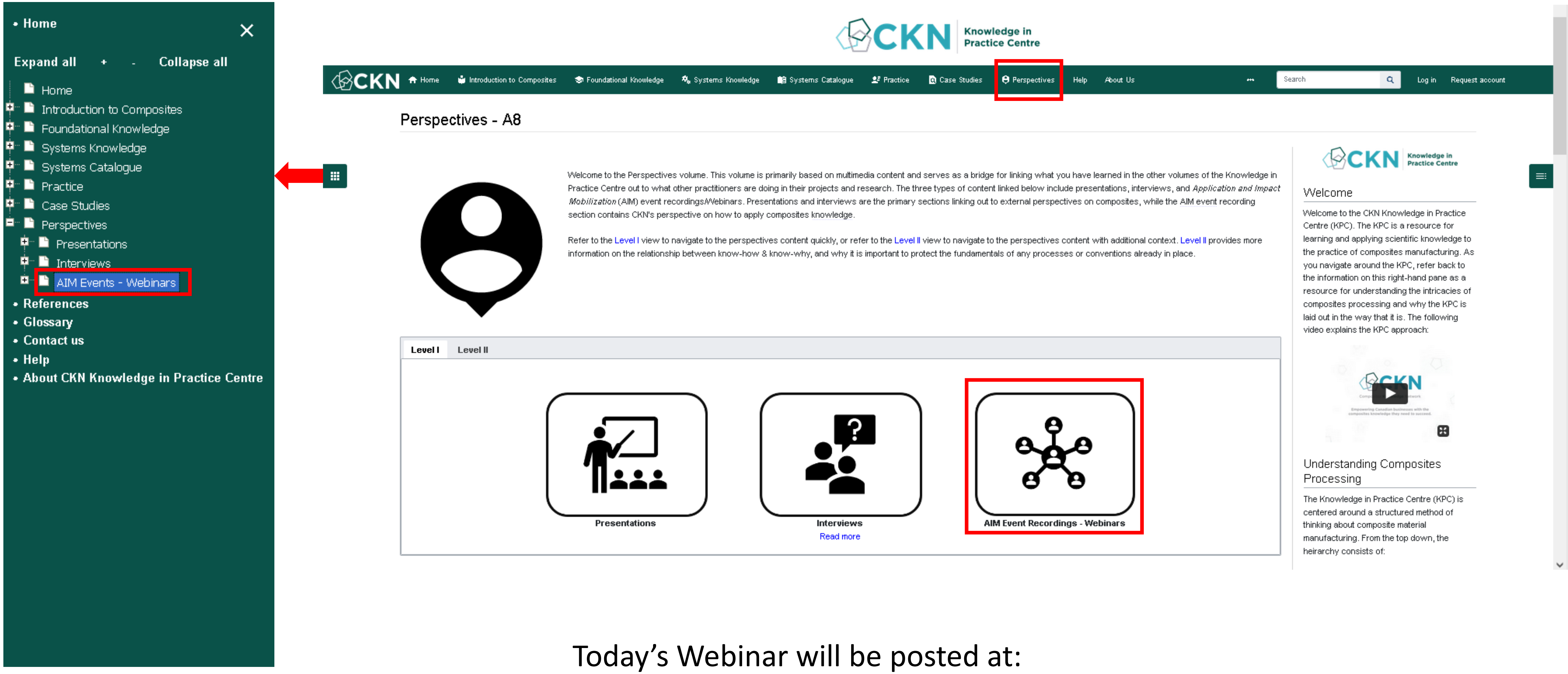
- A freely available online resource for composite materials engineering:

compositeskn.org/KPC

- Focus on practice, guided by foundational knowledge and a systems-based approach to thinking about composites manufacturing



PAST WEBINAR RECORDINGS AVAILABLE



Today's Webinar will be posted at:
https://compositeskn.org/KPC/A340

HOSTED BY: CKN Composites Knowledge Network

HOSTED BY: sampe Canada

TODAY'S TOPIC:

Introduction to Tooling for Composite Materials Processing

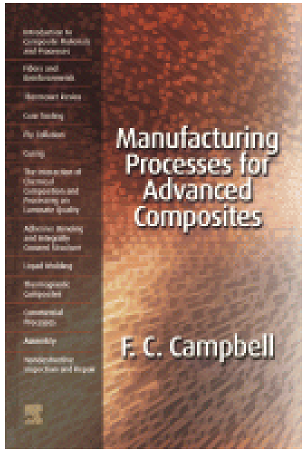
OUTLINE

- Introduction
- Requirements for a specific process
  - One sided tooling
  - Closed moulding
    - RTM
    - Light RTM
  - Compression moulding
- Tooling materials and construction methods
  - Composite
  - Metallic
  - Polymer
  - Wood
  - ‘Other’
- Comparison of various tooling materials

WHY SHOULD I CARE ABOUT TOOLING?

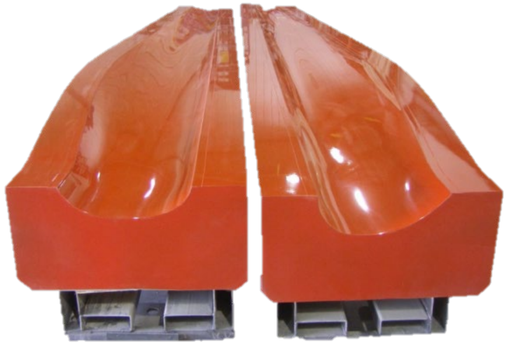
- Chapter 4 - Cure Tooling: You Can Pay Me Now …or Pay Me Later
  - *“Tooling for composite fabrication is a major up-front non-recurring cost. It is not unusual for a large bond tool to cost as much as $500,000–$1,000,000. Unfortunately, if the tooling is not designed and fabricated correctly, it can become a recurring headache, requiring continual maintenance and modifications, and, in the worst scenario, replacement.”* *-Flake Campbell*

- Get it right from the beginning or you will be paying for it until you do



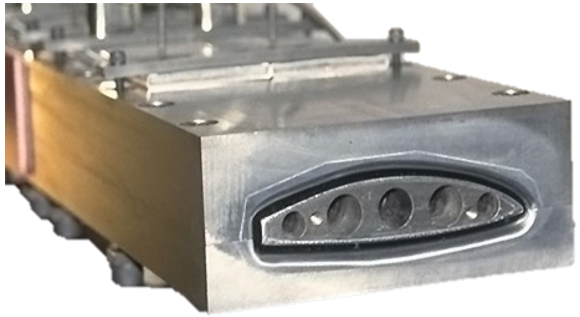
TERMINOLOGY

- The ‘tool’ generally refers to the physical object used to control the shape of a part
  - Mould
  - Mandrel
  - Die
  - Caul plates
  - Plug



Open mould

Plug



Pultrusion die

Caul plates

Mandrel

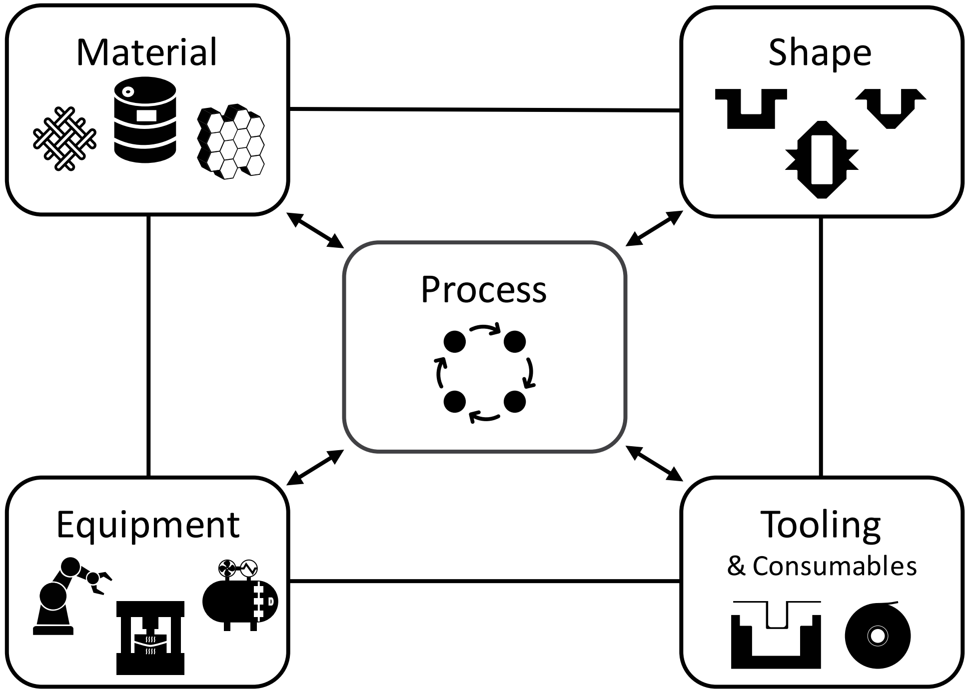
HOSTED BY: CKN Composites Knowledge Network

HOSTED BY: sampe Canada

TOOL FUNCTION

- Primary function is to provide shape to the part
- May also provide:
  - Alignment of fibre (assist in the deposition of the materials)
  - Alignment features for post processing
  - Fibre bed consolidation
  - Desired surface finish
- Must consider MSTEP, it all ties in together

MSTEP Approach

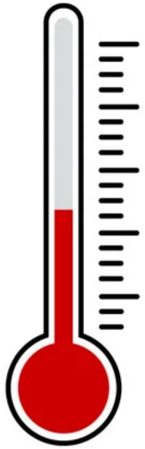


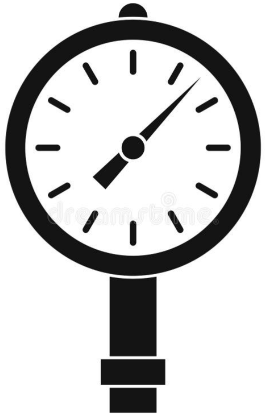
HOSTED BY: CKN Composites Knowledge Network

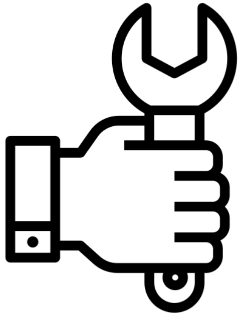
HOSTED BY: sampe Canada

BASIC REQUIREMENTS

- Compatible with intended process
  - Withstand temperature and pressure
  - Process specific requirements
  - Ie: accommodations for vacuum bag, vacuum tight
  - Must release from the part
  - Thermal response such that cure cycle specs are met
- Other requirements
  - Durability (enough to make production run)
  - Repairability
  - Maintainability

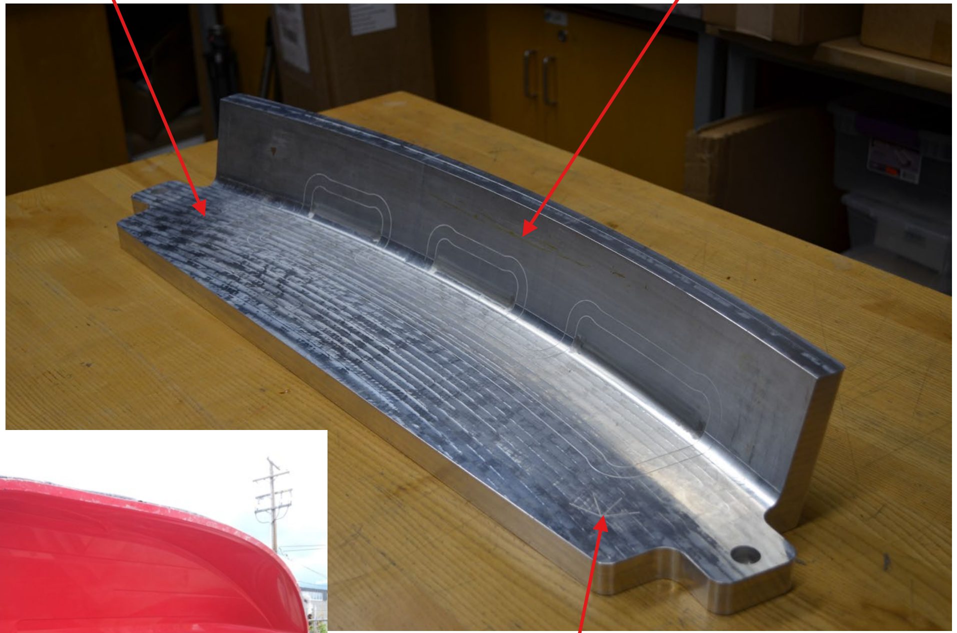


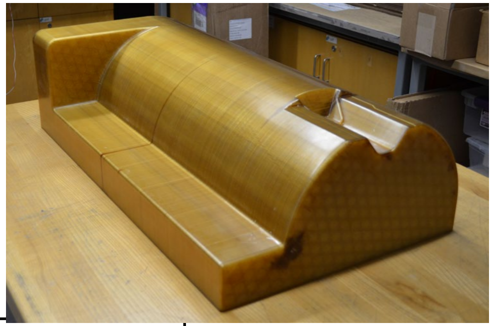




PROCESS SPECIFIC REQUIREMENTS: ONE SIDED TOOL

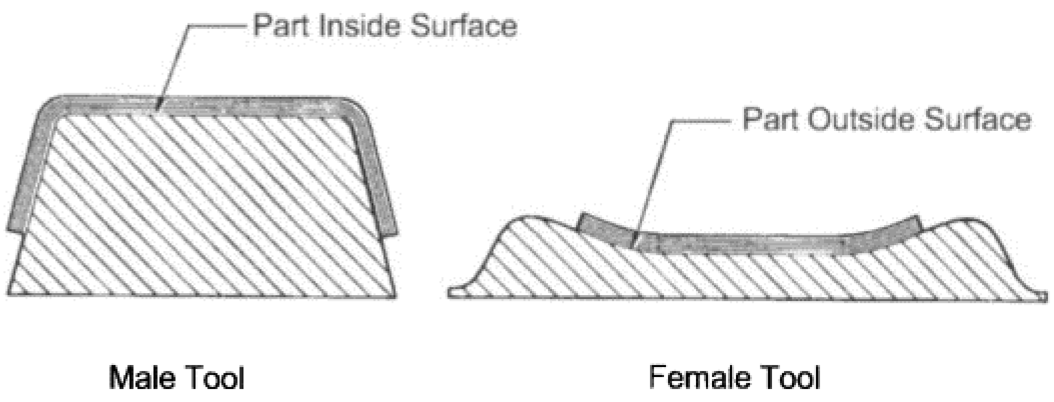
- Lowest requirements
- Control shape from one surface
- Withstand the curing conditions
- Vacuum tight if vacuum bag used
- Accommodate vacuum bag (if used)
- Accommodate post processing and assembly





PROCESS SPECIFIC REQUIREMENTS: ONE SIDED TOOL

- Need to consider which side of the part should be moulded
  - Ie. the inside surface or the outside surface
- OML – outer mould line
  - Control over outer surface of part, can be extremely smooth
- IML – inner mould line
  - Control over inner surface may assist with assembly (reduced shimming)

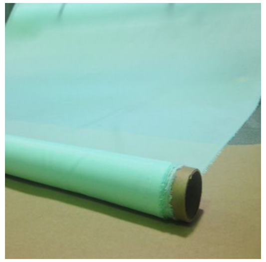


*

*F. Campbell, Manufacturing Processes for Advanced Composites

PROCESS SPECIFIC REQUIREMENTS: ONE SIDED TOOL

- One sided tools are commonly used with a vacuum bag to provide consolidation pressure to the laminate during cure
- Vacuum bags are typically used in conjunction with:
  - Peel ply or release film
  - Breather cloth
  - Tacky tape
  - Vacuum ports and hoses

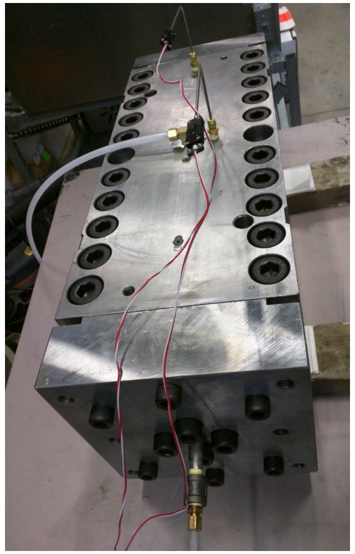


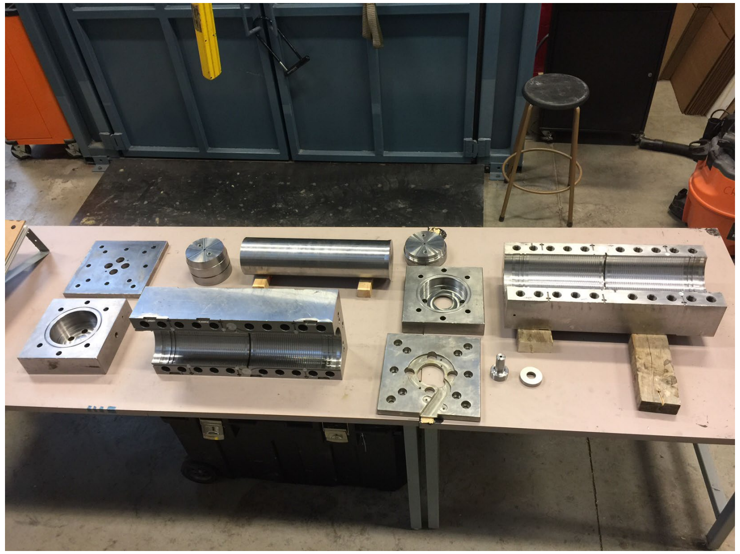

- Considerations:
  - Process compatibility → temperature requirements
  - Material compatibility

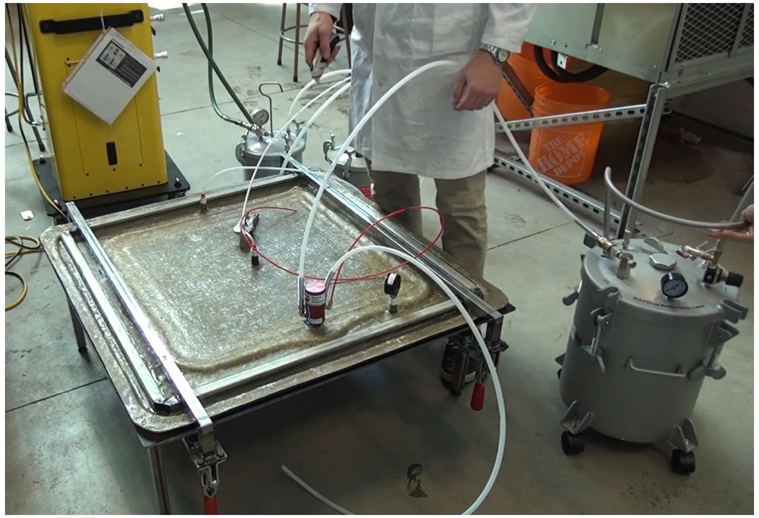



PROCESS SPECIFIC REQUIREMENTS: CLOSED MOULDING

- RTM
  - Typically metallic
  - Higher pressure
  - Typically cured at elevated temperatures
- Light RTM
  - Glass fibre/polyester
  - Intended for room temp cure
  - Typically up to 1 atm
  - B side is thin and flexible, so the incoming pressure cannot be very high
  - Typically made by making a one sided tool, then a B side off that tool

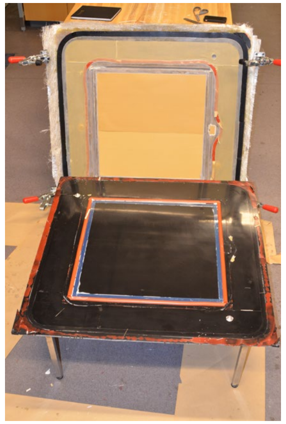


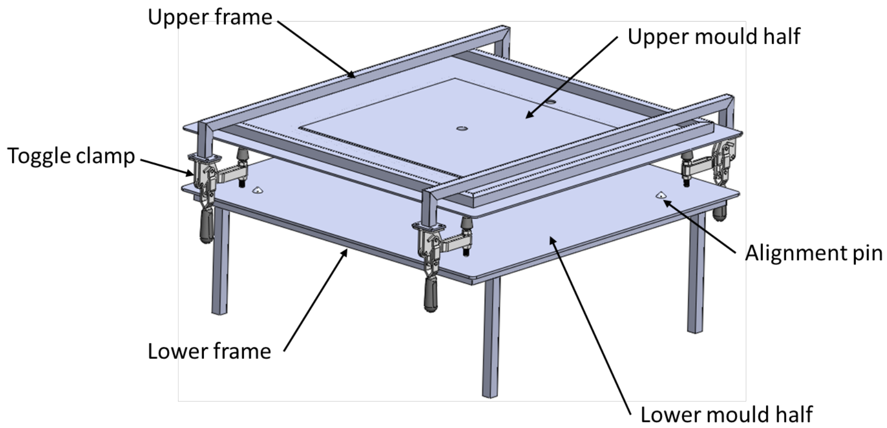


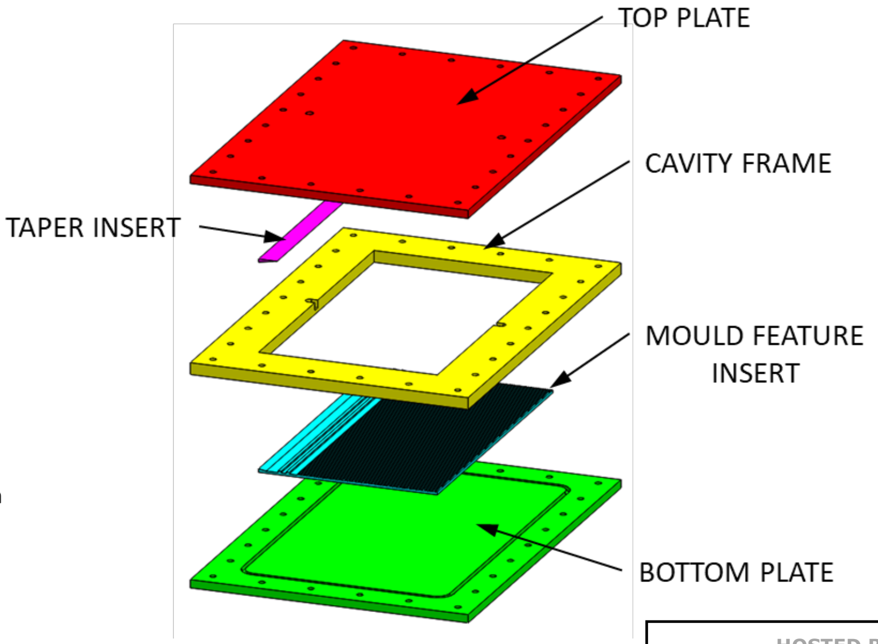


PROCESS SPECIFIC REQUIREMENTS: CLOSED MOULDING

- Designed for a specific laminate and near net shape parts
- Typically a seal/gasket (O-ring) between mould halves
- Need to withstand internal pressure and separation forces (may require external support/structure)
- Racetracking is inherent to the process, must be accounted for
- Inlet and outlet location strategies are critical
- Flow simulations can be done

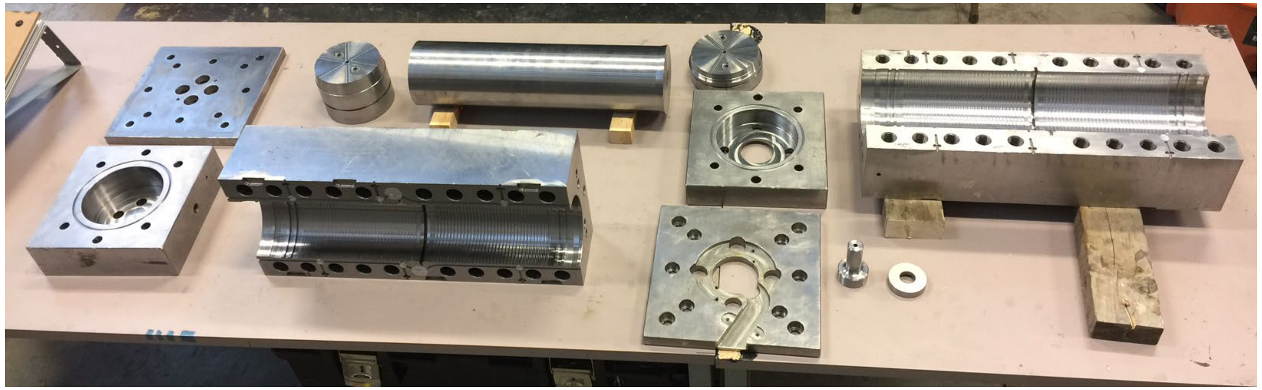


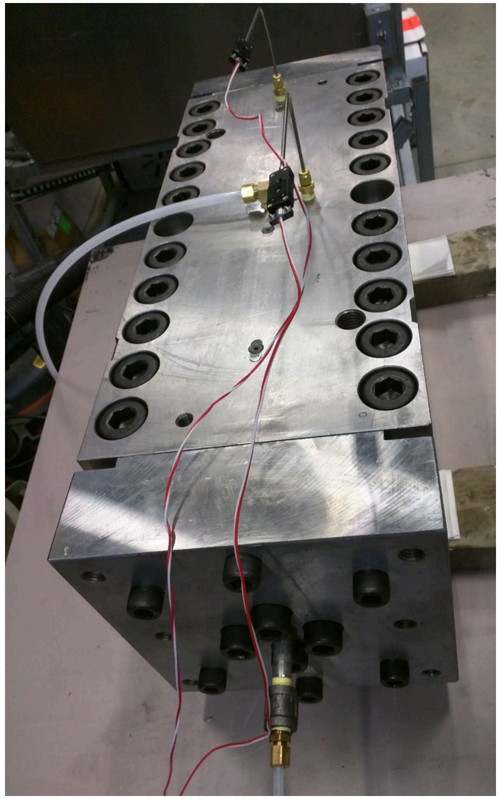


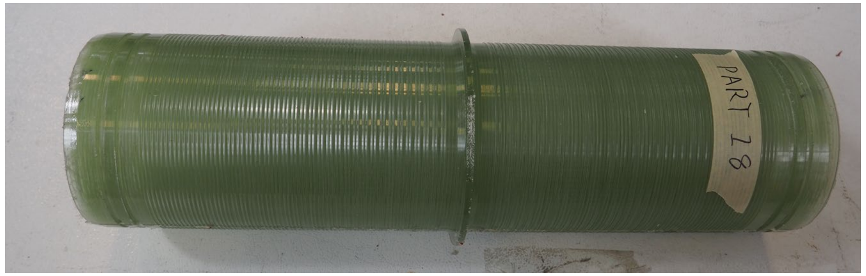


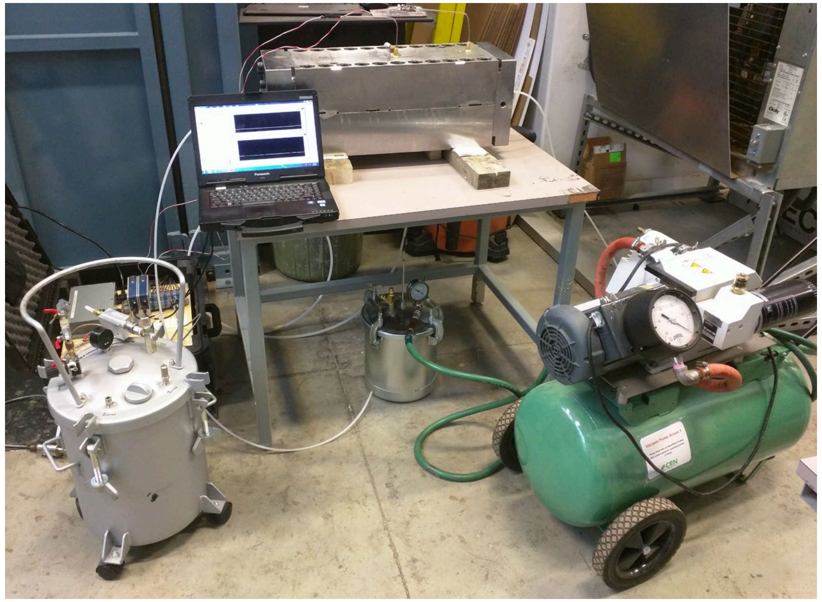
PROCESS SPECIFIC REQUIREMENTS: CLOSED MOULDING

- Metallic RTM tool



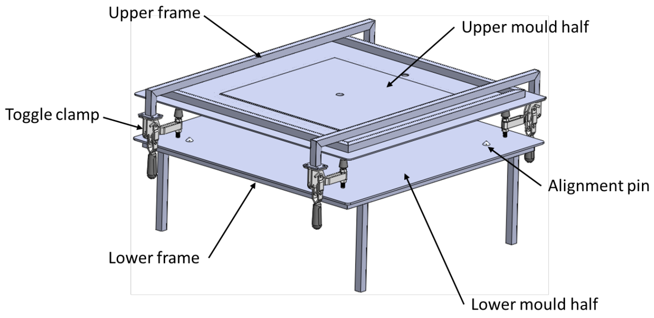


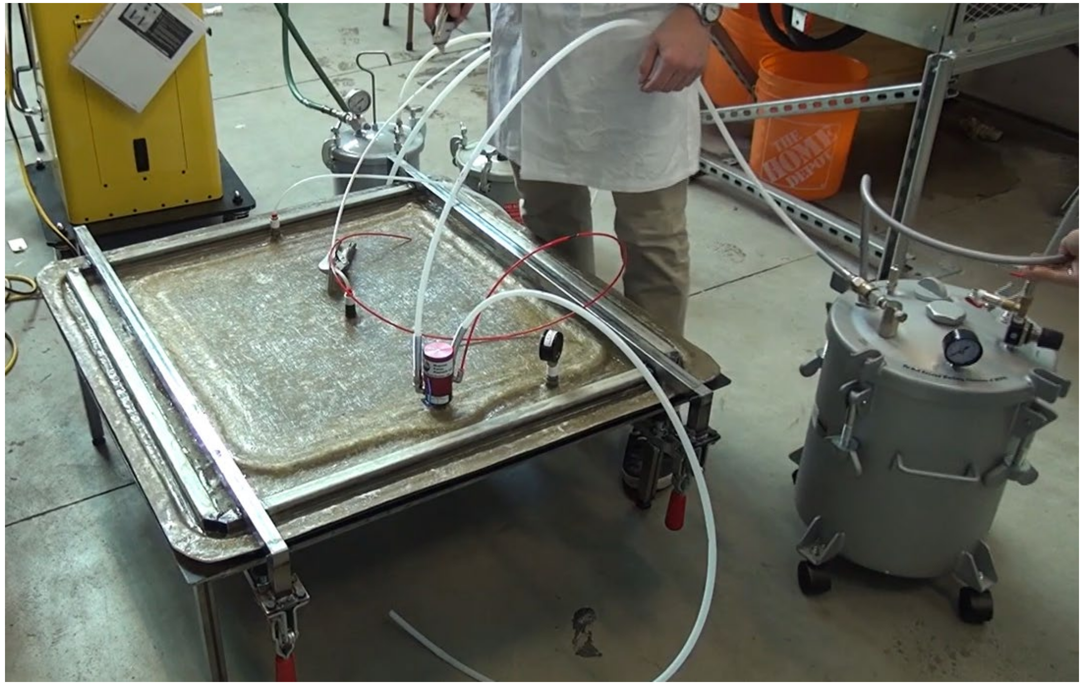


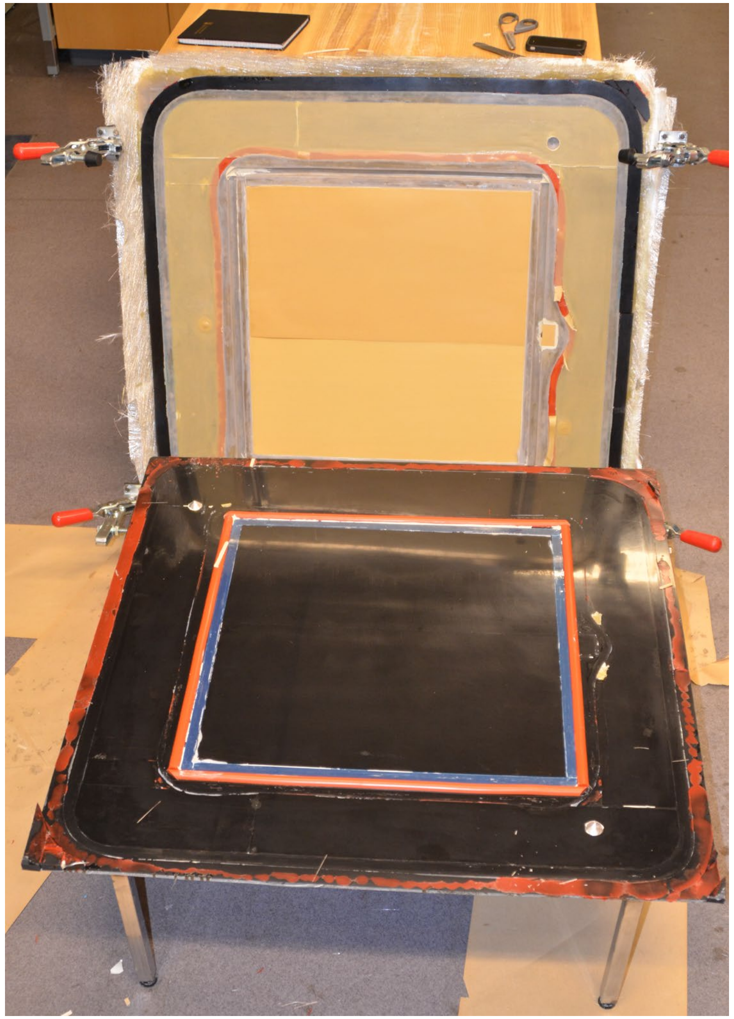


PROCESS SPECIFIC REQUIREMENTS: CLOSED MOULDING

- Composite Light RTM tool





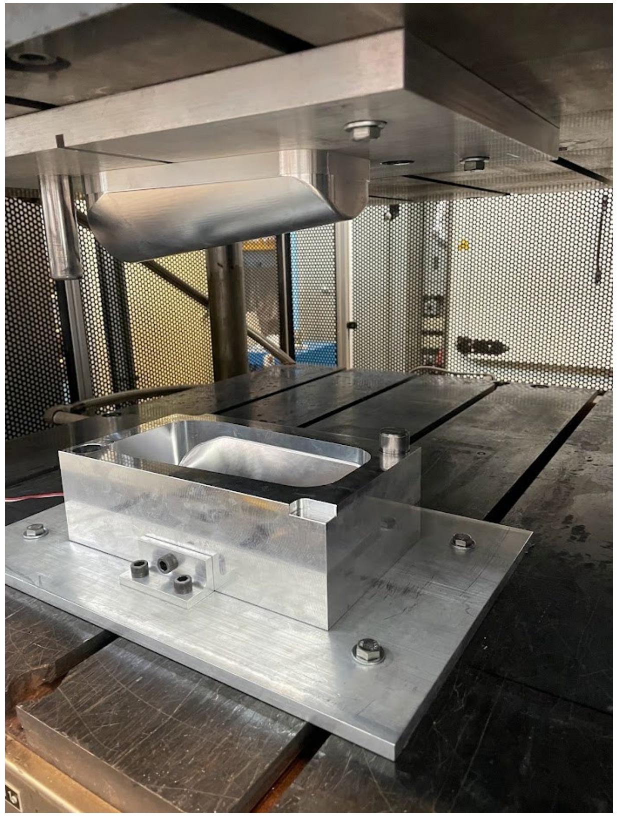


HOSTED BY: CKN Composites Knowledge Network

HOSTED BY: sampe Canada

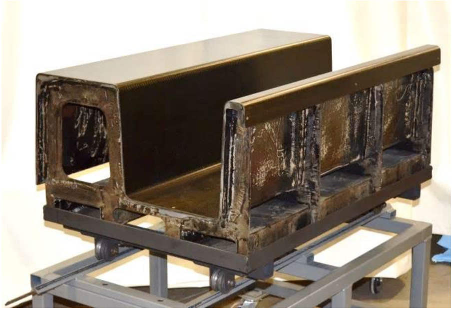
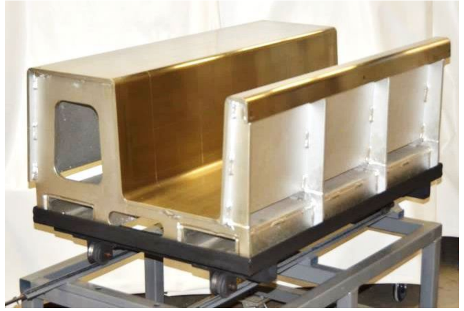
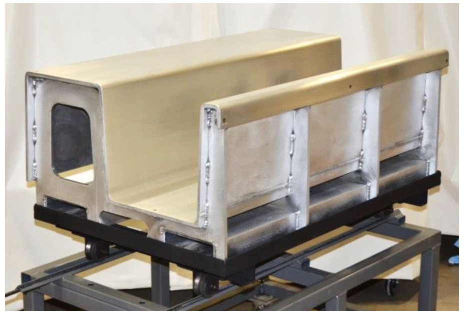
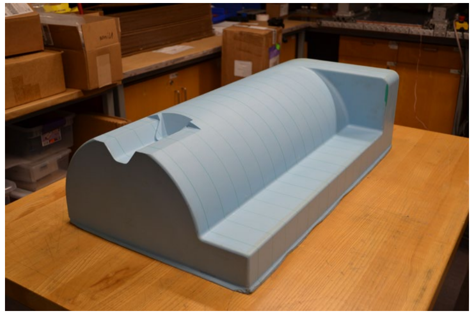
PROCESS SPECIFIC REQUIREMENTS: COMPRESSION MOULDING

- Withstand high temperature and pressure
- Alignment is important
- Typically done in a hot press
- Typically metallic



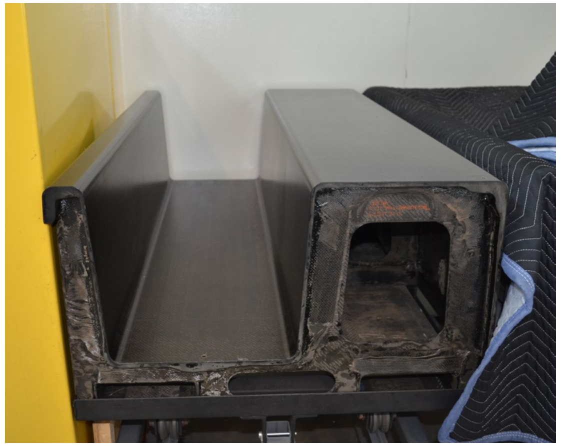
TOOLING MATERIALS & CONSTRUCTION METHODS

- Materials:
  - Composite – glass/polyester to carbon/epoxy
  - Metallic – invar, aluminum, steel
  - Polymer – cast, 3D print, tooling board
  - Wood – lumber, plywood, MDF (medium density fibreboard)
  - Other

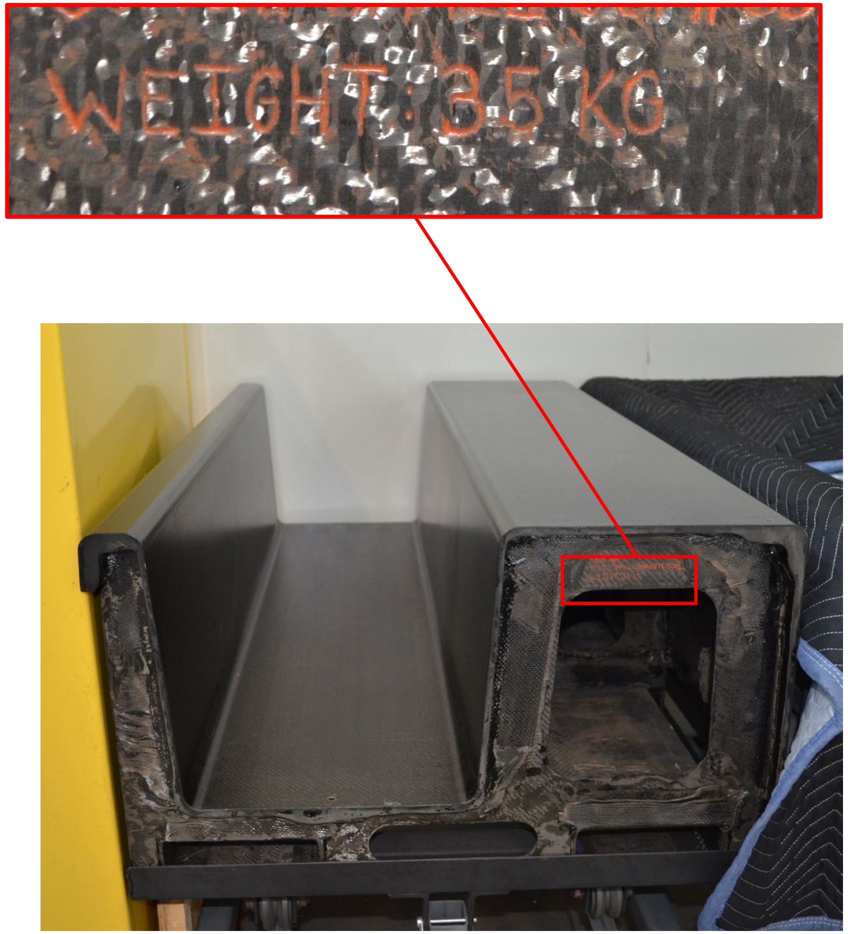

COMPOSITE TOOLING

- Common materials
  - Glass/Polyester – Suitable for economical parts with lower requirements
  - Carbon/Epoxy – Suitable for high quality parts



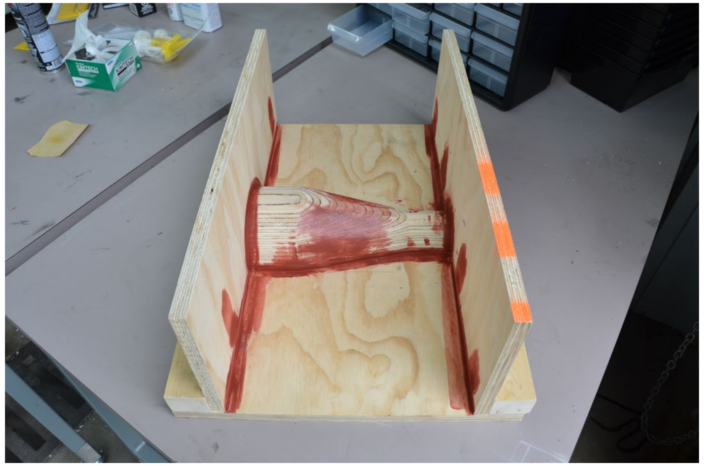
COMPOSITE TOOLING

- Pros
  - Cost effective (typically)
  - Suitable for lower production runs
  - Repairable
  - Well suited to large geometries
  - Lighter than many alternatives
  - Low thermal mass
- Cons
  - Challenges maintaining shape
  - Less durable than metallic
  - CTE is directional
  - Poor thermal conductivity



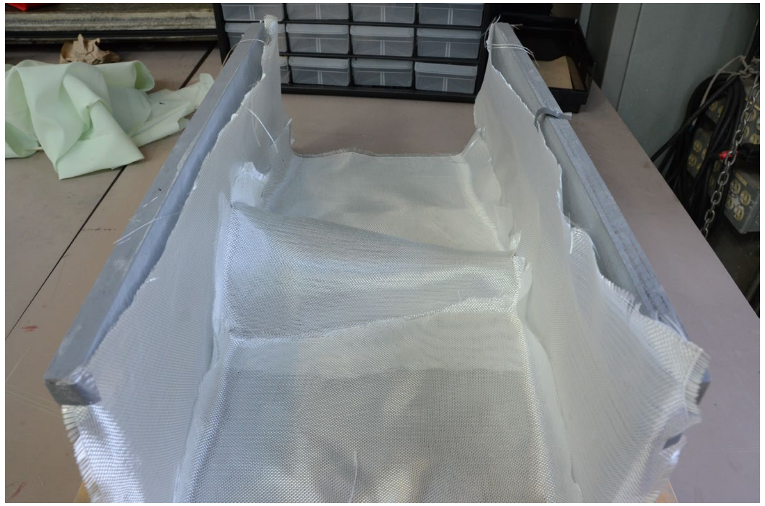
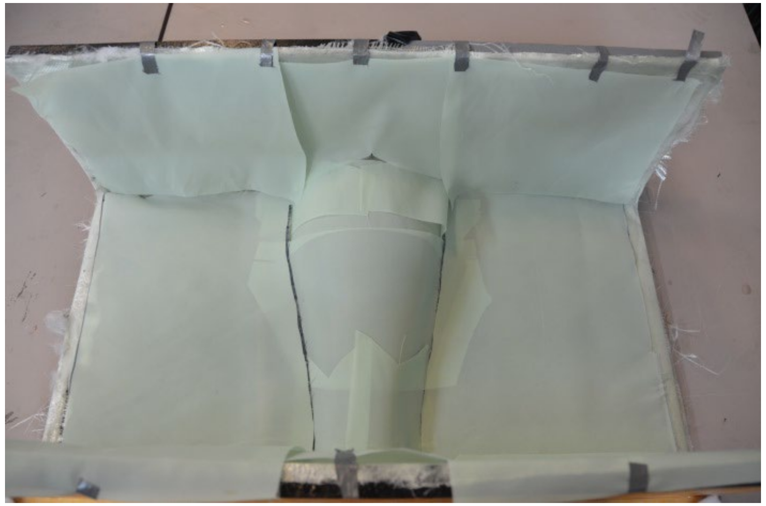
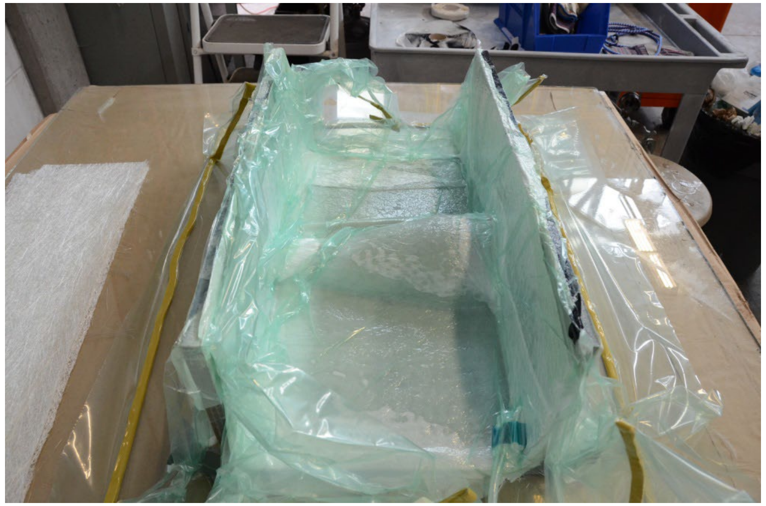
COMPOSITE TOOLING

- Manufacturing process
  - Typically start by making a plug
    - Hand shape, 3D print or CNC
    - Assemble and fair out surface
    - Apply primer
    - Apply mould release



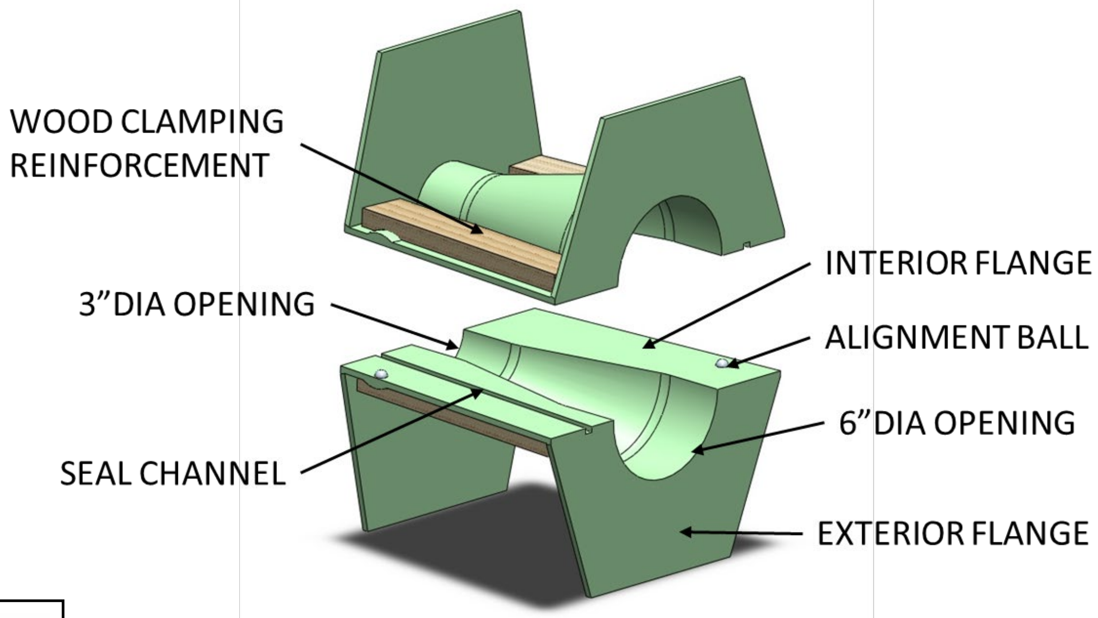
COMPOSITE TOOLING

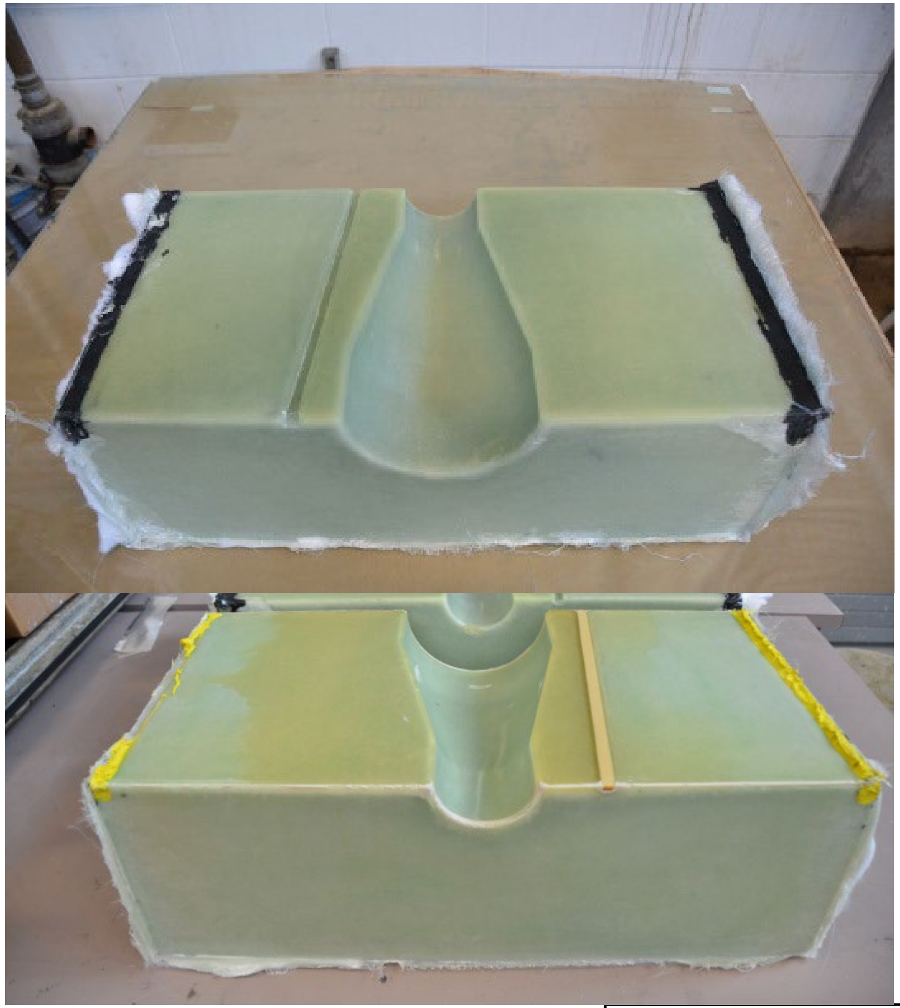
- Manufacturing process
  - Apply gel coat and allow to partially cure
  - Layup composite
    - Wet layup, infusion or prepreg are good options
  - Cure the composite

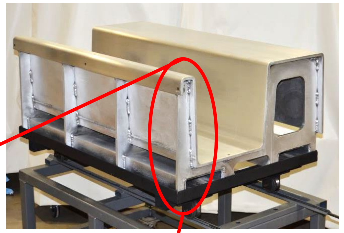
COMPOSITE TOOLING

- Manufacturing process
  - Demould
  - Post processing
    - Trimming and machining
    - Install alignment and clamping considerations

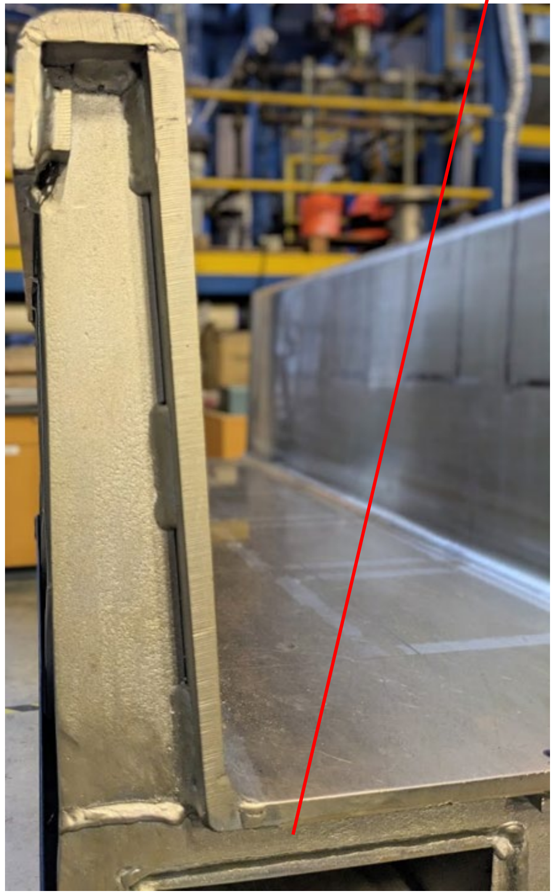


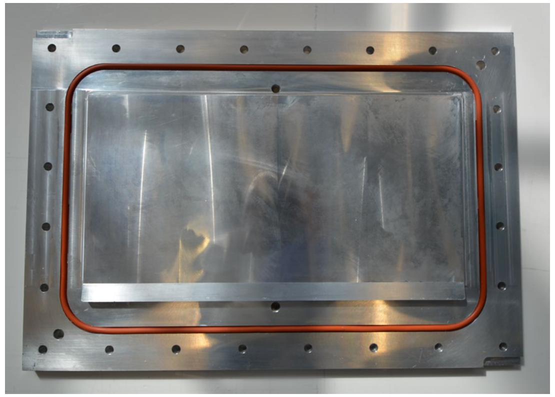


METALLIC TOOLING



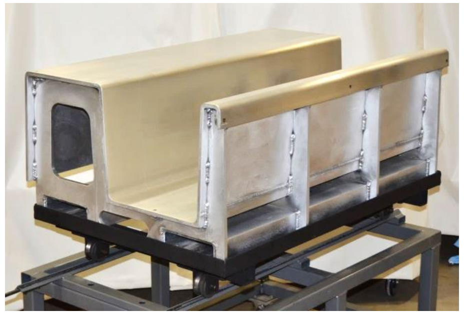
- Common materials:
  - Aluminum
  - Invar
  - Steel
- Material forms:
  - Billet
  - Plate
  - Sheet metal
  - Cast



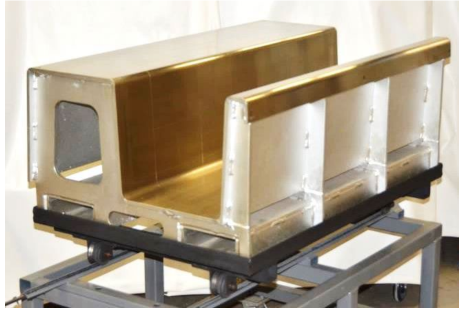


METALLIC TOOLING

- Pros
  - Durable
  - Dimensional control
  - Uniform CTE
  - CTE matching (Invar)
  - Thermal conductivity
- Cons
  - Expensive
  - Heavy
  - High thermal mass



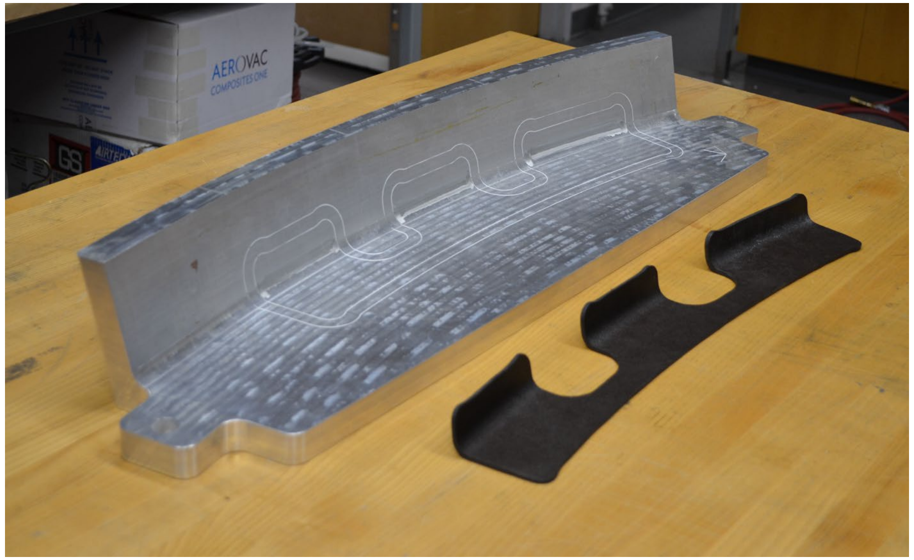
120 kg (260 lb)



410 kg (900 lb)

METALLIC TOOLING

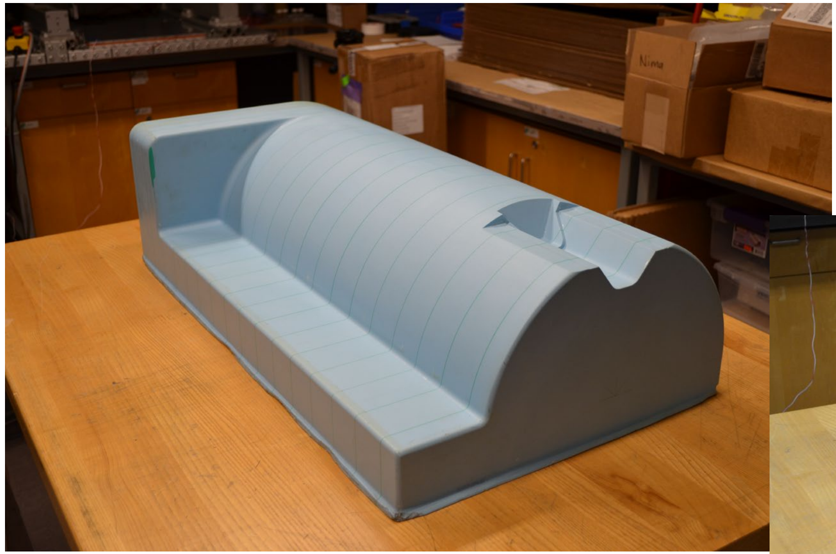
- Common processes
  - CNC from a billet
  - Cast into near net and CNC machined
  - Sheet Metal
  - Welded plate
  - Post processing by hand to polish and sand

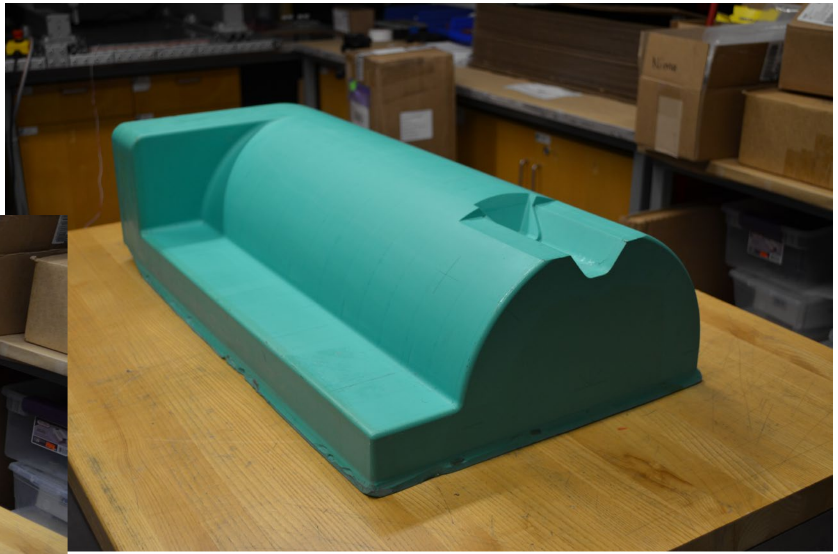


Tooling material	Density (kg/m^3)	Specific heat capacity (J/kg-K)	Thermal conductivity (W/m-K)	Coefficient of thermal expansion - CTE (x10^{-6}/°C)	Thermal diffusivity (x10^{-6}m^2/s)
Invar	8000	515	11.0	0.6-1.5	2.67
Mild steel	7850	510	55	11	13.7
Aluminum	2710	896	167	23	68.9

POLYMER TOOLING

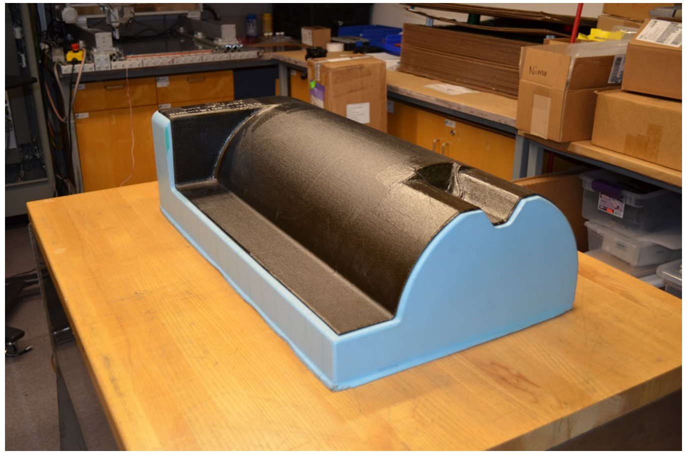
- Types
  - Foam – CNC or manually shaped
  - 3D Print – ABS/ASA, polycarbonate, ULTEM 9085 & 1010
  - Resin cast

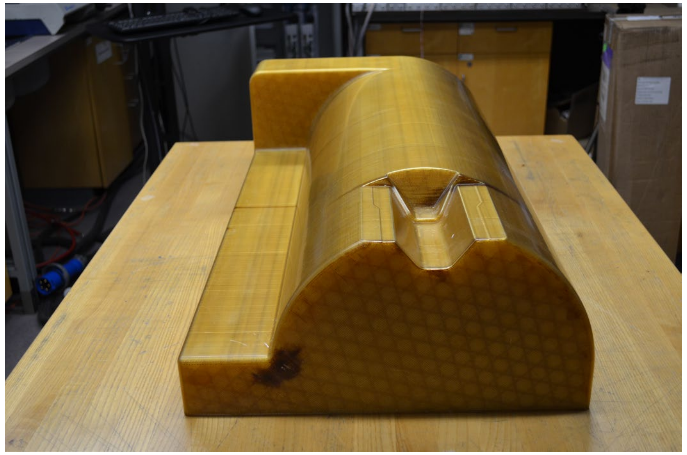




POLYMER TOOLING

- Pros
  - Economical
  - Typically fast to manufacture
  - Can be used for autoclave thermoset processing in some cases
- Cons
  - High CTE
  - Short lifetimes (low number of cycles)
  - Surface may need attention after each cycle



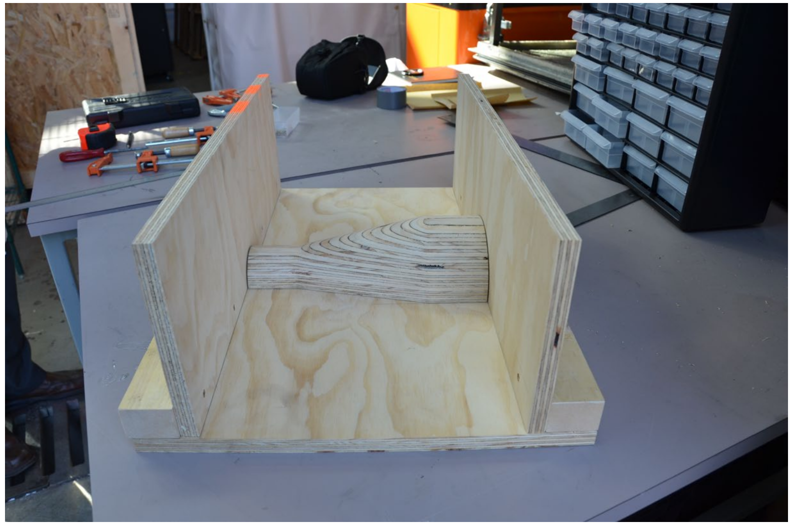


POLYMER TOOLING

- Process
  - Starting with a CAD model of the final part, determine the layup surface, edge of part (EOP) and trim area
  - Establish EOP and trim area by extending the surfaces
  - Thicken the tool surface, based on your needs and the size of the tool
  - Add stabilizing features, eg legs and edges
  - Add other features, eg thermocouple channels, guide pins and holes, and edges for demolding
  - Add fillets and round corners
  - 3D print or CNC tool
  - Sand and seal 2-3 times
  - Sand and polish for final surface finish

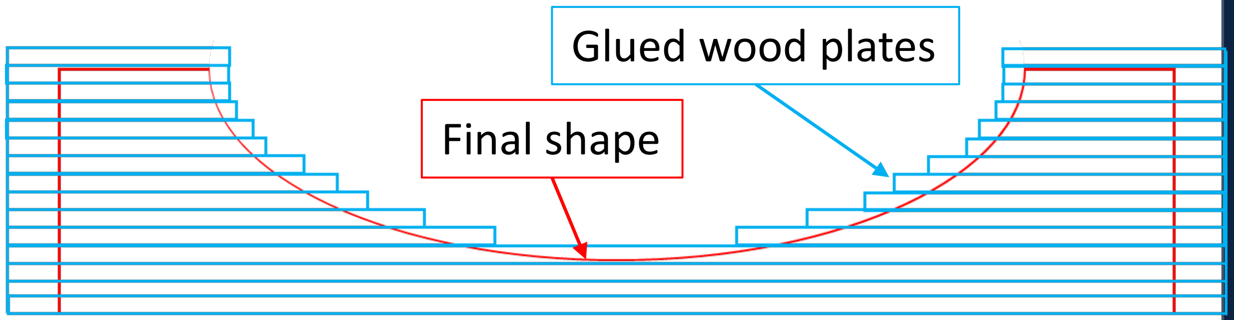
WOOD TOOLING

- Materials
  - MDF (medium density fibreboard)
  - Plywood
  - Lumber
- Cons
  - Limited life time
  - Sensitive to moisture and temperature changes
  - Labour intensive
- Pros
  - Economical
  - Can be produced with basic equipment
  - Relatively fast to manufacture
  - Materials are readily available



WOOD TOOLING

- Process
  - Wood sheet is arranged in the general shape of the tool to allow the final shape to be machined or manually cut from the stack
  - Pieces are bonded together (epoxy, wood glue, etc.)
  - Assembly is clamped or vacuum bagged
  - Sometimes referred to as “glue-ups”
  - The final shape is machined
  - The wood is then sealed, usually with an epoxy coating or a polyester sealer
  - The surface is finished, various options include:
    - Wet layup of a single ply of glass fibre
    - Epoxy coating
    - Release film laid or glued to the tool
    - Packing tape



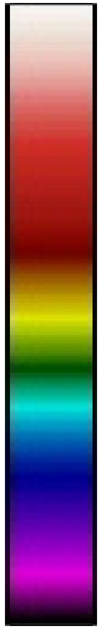
OTHER

- Dissolvable cores
  - Some are water soluble
  - Some can be 3D printed
- Bladders
  - Silicone, latex, other
  - Need to consider how the bladder is moulded as well
- Caul plates
  - Thin sheet metal or composite
  - Improve surface finish
  - Smooth out ply drop downs
- Pressure intensifiers
  - Typically elastomeric
  - Used in areas that are difficult to vacuum bag (bridging concerns)
- Consumables

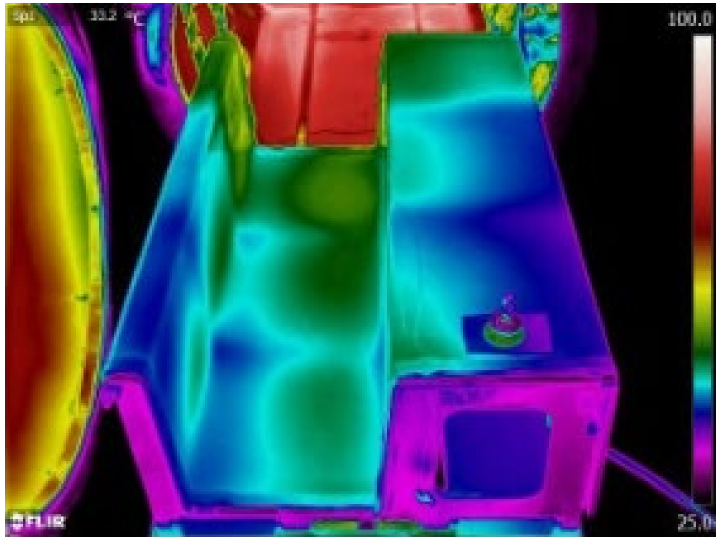
THERMAL CONSIDERATIONS

- Three tools were ramped up in temperature before an IR image was taken

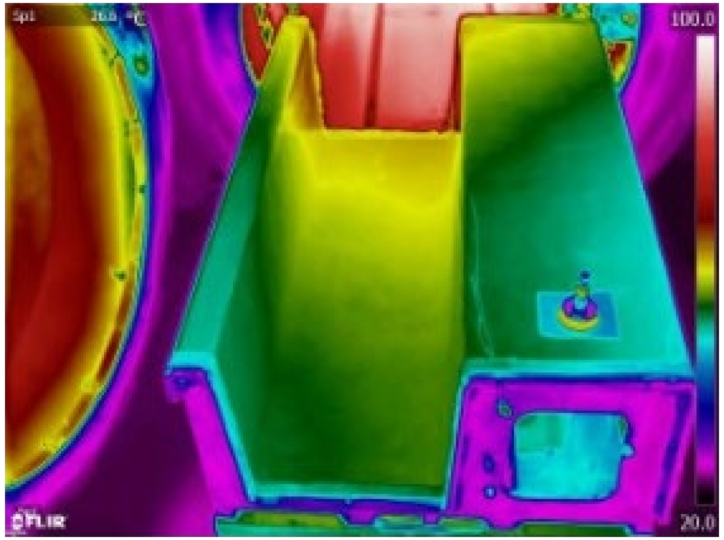
100 ^{o}C



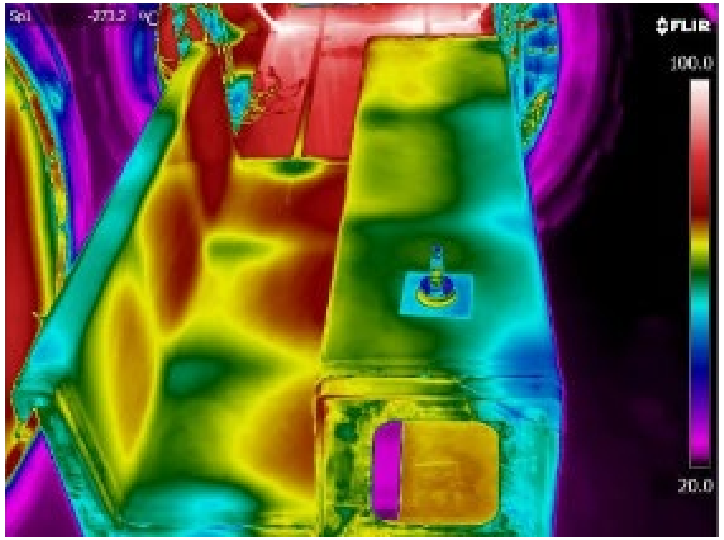
20 ^{o}C



Invar



Aluminum



CFRP

COMPARE

Tooling material	Cost	Durability	Weight	Thermal mass	Thermal conductivity	Coefficient of thermal expansion (CTE)	Thermal diffusivity
Invar	$$$	Excellent	Heavy	High	Moderate	Low	Low
Steel	$$$	Excellent	Heavy	High	Good	Moderate	Moderate
Composite	$	Low	Light	Low	Low	Moderate	Low
Aluminum	$$	Good	Moderate	Moderate	Excellent	High	High

CONCLUSION

- That was a high level introduction to tooling
- Important to keep in mind the various considerations specific to the intended process
  - One sided tool for prepreg curing in an autoclave has different requirements than an RTM tool, which are different than a compression moulding tool…
- It is also important to be aware of the different tooling material choices
  - Which is right for your application?

Thank you for joining us!

Keep an eye out for upcoming AIM events:

Introduction to Bonding Composite Materials
Hosted by Dr. Casey Keulen
October 25, 2023
https://compositeskn.org/KPC/A341

And don't forget to visit the KPC for more information:

https://compositeskn.org/KPC

Today's Webinar will be posted at:
https://compositeskn.org/KPC/A340

HOSTED BY: CKN Composites Knowledge Network

HOSTED BY: sampe Canada