AN OVERVIEW OF COMPOSITE TOOLING CONSTRUCTION

CO-HOSTED BY:

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YOUR HOST

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- Ph.D. and M.A.Sc. in Composite Materials Engineering
- Nearly 20 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

SLIDE CONTRIBUTORS

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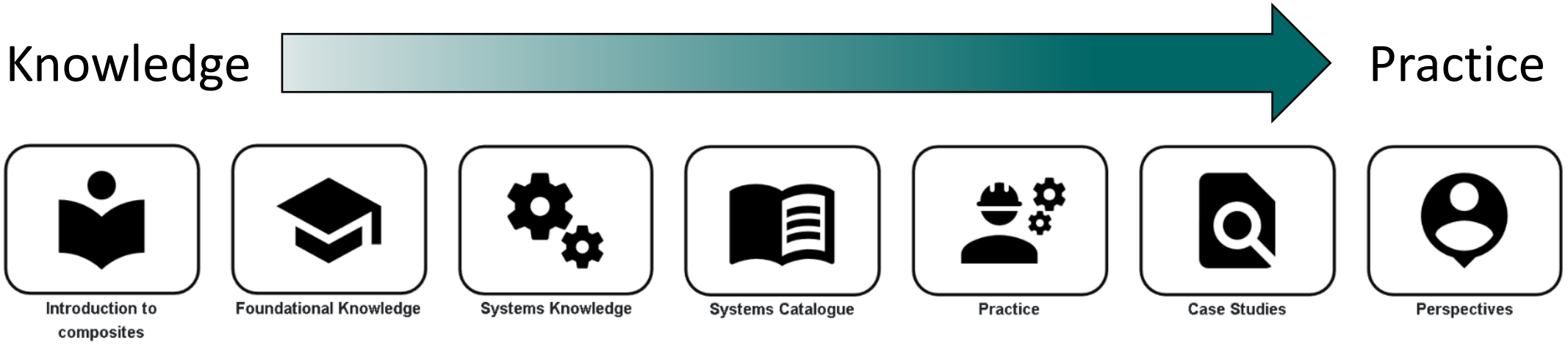
- Shayan Fahimi
  - CKN Research Engineer

KNOWLEDGE IN PRACTICE CENTRE (KPC)

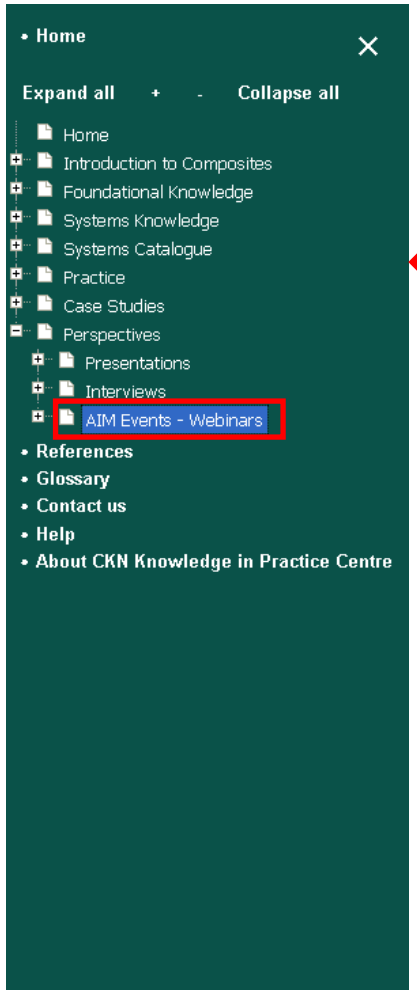
- A freely available online resource for composite materials engineering:

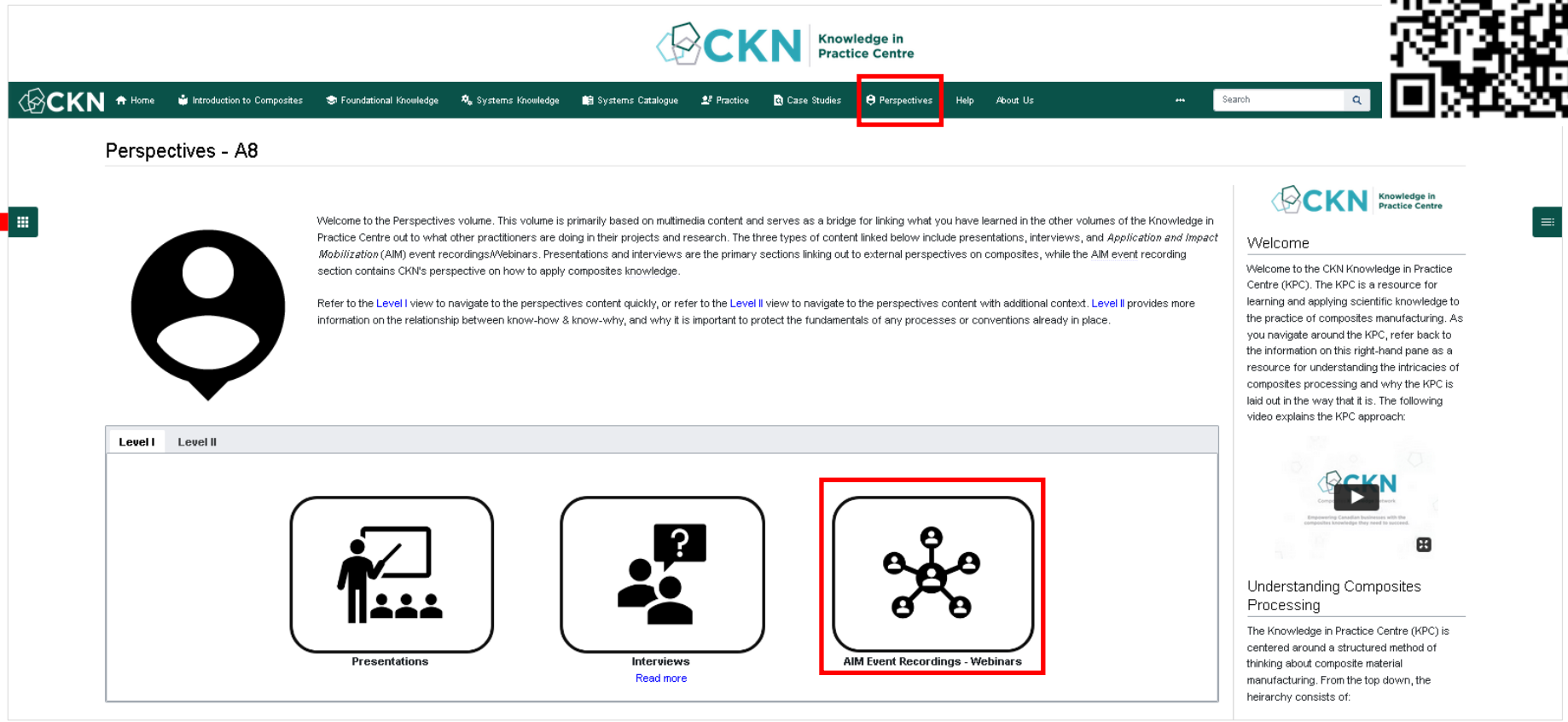
compositeskn.org/KPC

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



PAST WEBINAR RECORDINGS AVAILABLE





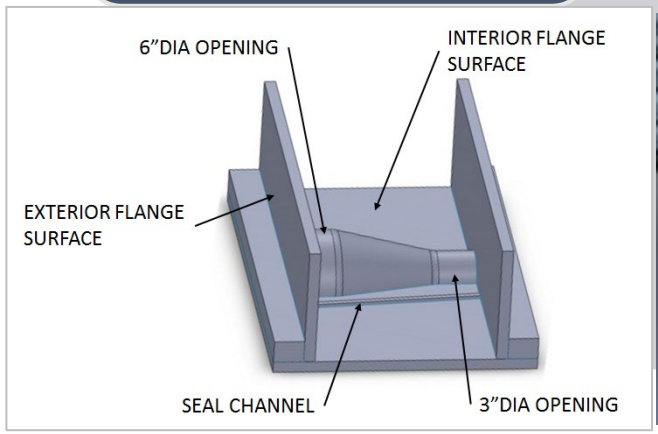
Today's Webinar will be posted at:
https://compositeskn.org/KPC/A396

TODAY'S TOPIC:

An Overview of Composite Tooling Construction

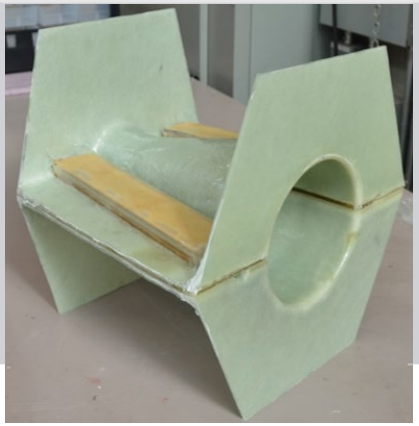
WORKFLOW OF COMPOSITE TOOL MAKING

Tool and Plug Design

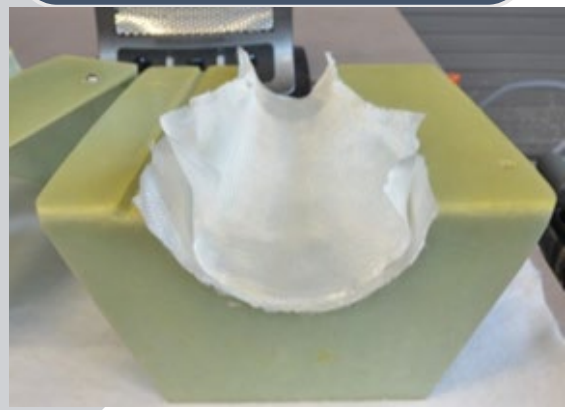


Plug Fabrication

Tool Fabrication



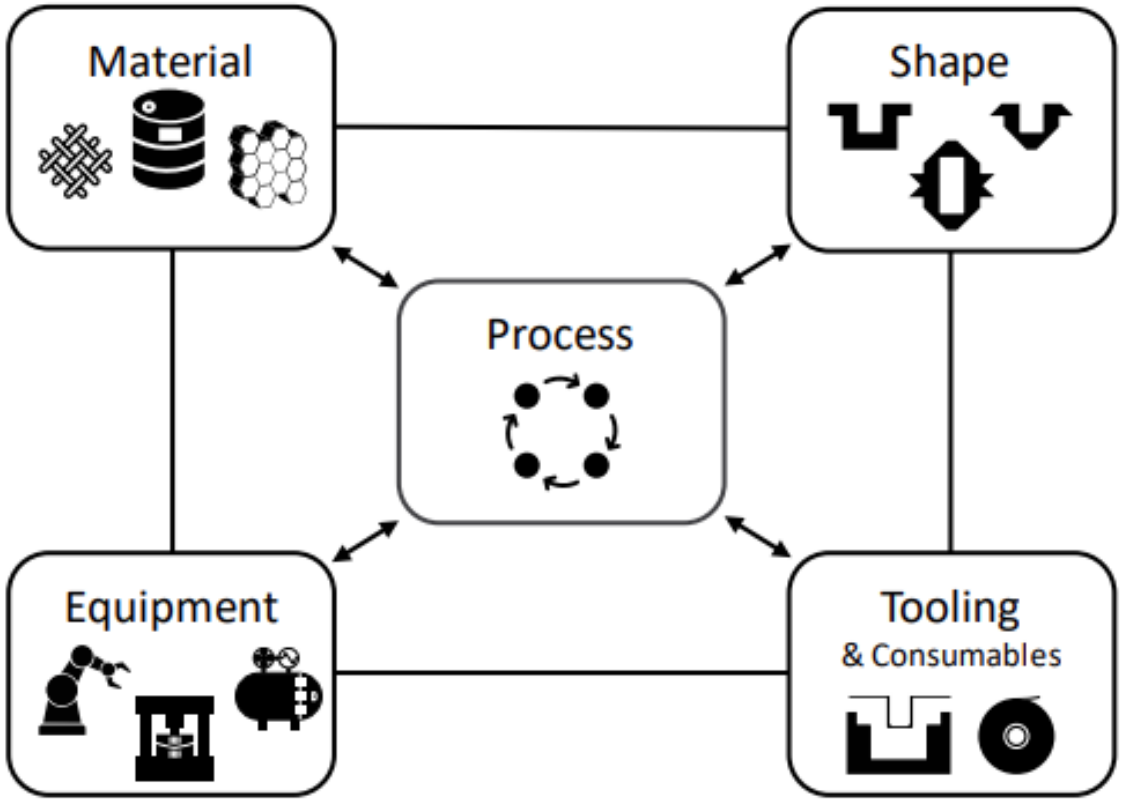
Operation/ Maintenance



RECAP OF INTRODUCTION TO TOOLING

- Tools → provide shape to the part (part of the MSTEP approach)
  - Why care? Get it right from the beginning or you will be paying for it until you do
- Part of the MSTEP approach

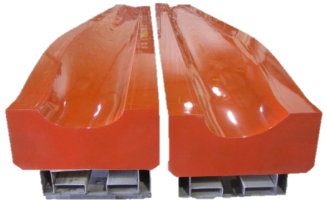
Introduction to Tooling For Composite Materials
https://compositeskn.org/KPC/A340



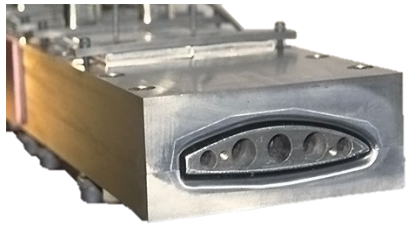
IMPORTANT TERMS

- Tool: The physical object used to control the shape of a part
  - Mould/mold
  - Mandrel
  - Die
  - Caul plates
  - Plug

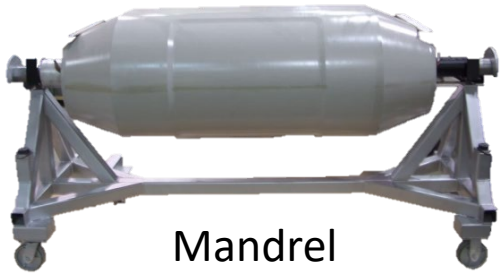
Plug



Open mould



Die



Mandrel

Caul plates

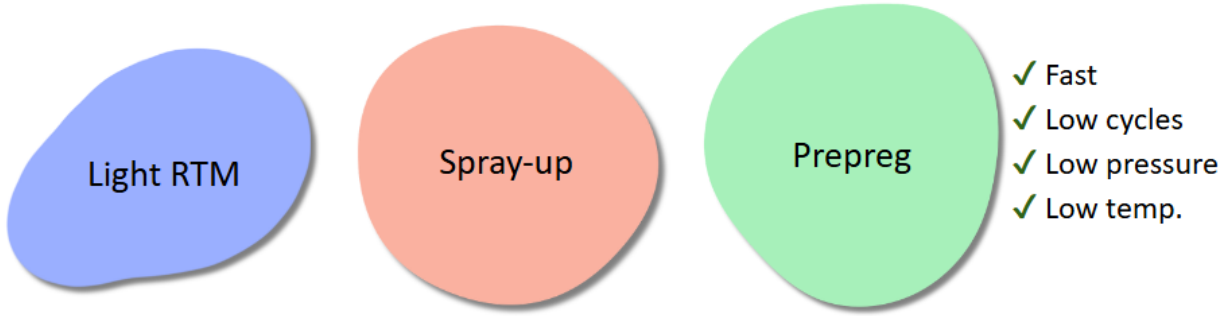
WHAT IS A COMPOSITE TOOL

Composite tools: Tools made of composite materials usually used to make composite parts

Key features:

- Control surface finish
- Control dimensional accuracy
- Low unit cost and high production rate for high part volume
- Usually cheaper to correct a tool than to correct the part

Typically used for:



Typically not used for:

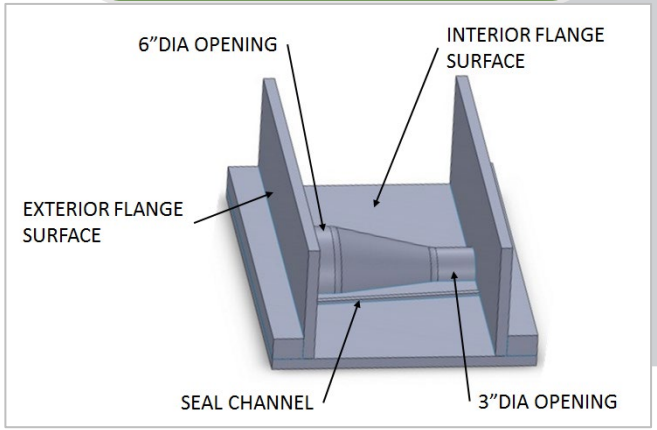
WORKFLOW OF COMPOSITE TOOL MAKING

Design

Plug Fabrication

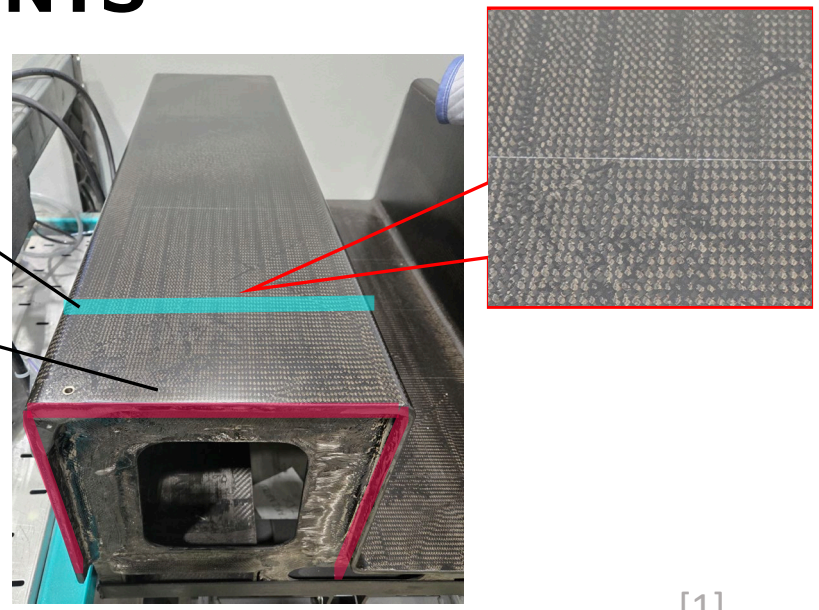
Tool Fabrication

Operation/ Maintenance

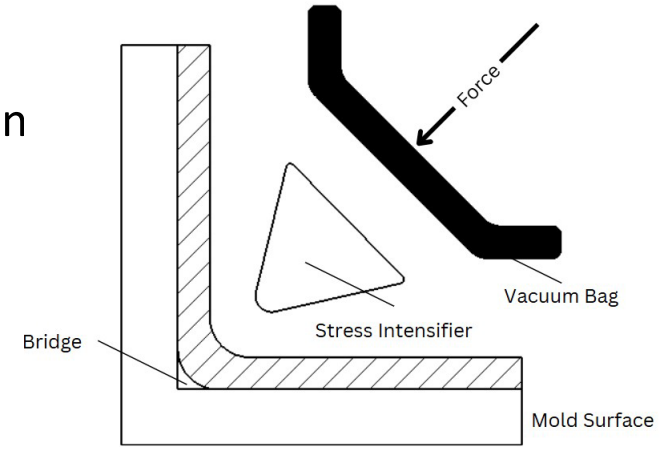


GENERAL REQUIREMENTS

- Part geometry and tool features
  - Flange size and configuration
  - Parting and trim lines
  - Scribe lines
- Component tolerances
  - Allowance for thermal effects (CTE, springback, etc.)
  - Resin shrinkage (linear or volume shrinkage % usually given)
- Location of holes, rails, and attachments
  - Location for supporting frames for mounting, handling, and tran
  - Part removal components (Ie. flex areas)
- Avoid sharp corners/tight radii to reduce bridging
  - Use stress intensifier to reduce bridging



[1]

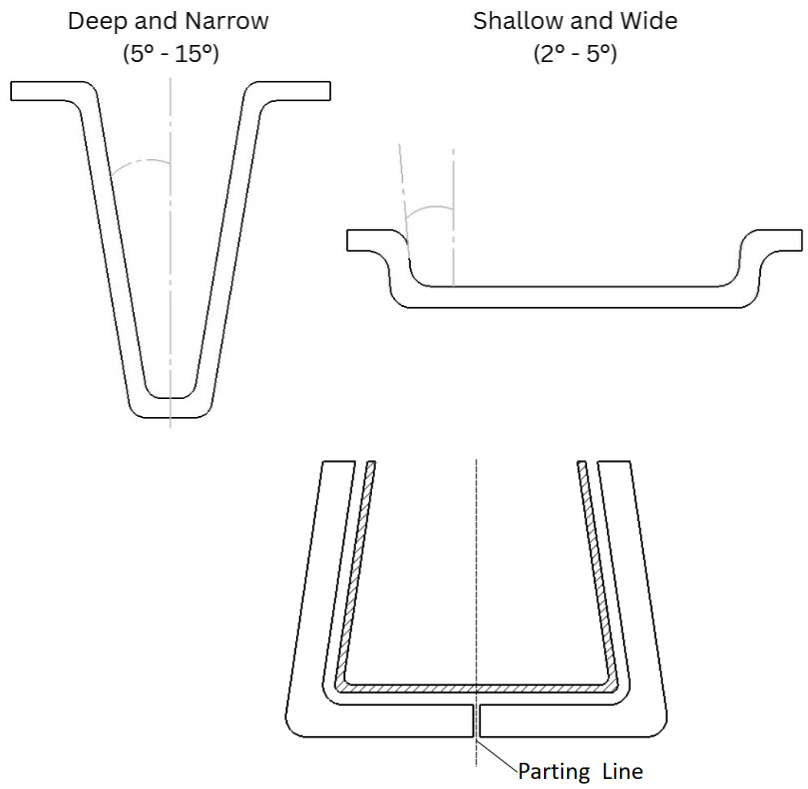


[1] Adapted from https://link.springer.com/chapter/10.1007/978-3-030-78807-0_6

DRAFT ANGLES AND PARTING LINES

- Draft angle → angle between walls and release direction
- Shallow and wide parts should have a draft angle of 1 degree or more (2-5 degrees recommended)
- Narrow and deeper moulds need larger draft angles (5-15 degrees)
- Negative drafts should be avoided
  - If necessary, use a parting line to separate into moulds with positive draft angle

[1]



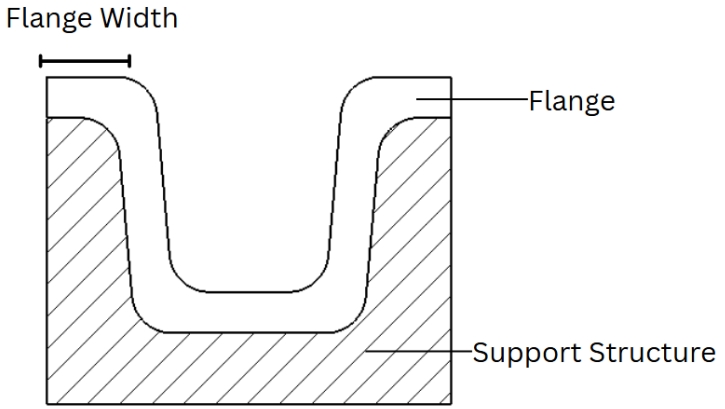
[1] Adapted from Wanberg, John. Composite Materials Fabrication Handbook #2

FLANGES

- **Flanges:** Wide, flat sections extending from mould surface
  - Surface for adhering/attaching accessories (ie. Vacuum bags)
  - Room for excess material
  - Locating (registering) and joining multiple sections
  - Makes tooling more rigid
  - Strengthen mould lip → greater life and better demoulding
- **Flange width:**
  - No vacuum bag: 25 – 50 mm (1 – 2 in.)
  - Regular vacuum bagging: 50 – 100 mm (2 – 4 in.)
  - Vacuum infusion: 150 – 200 mm (6 – 8 in.)

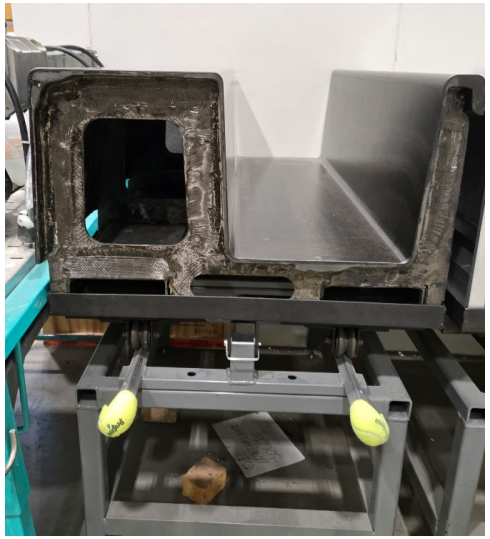
[1]

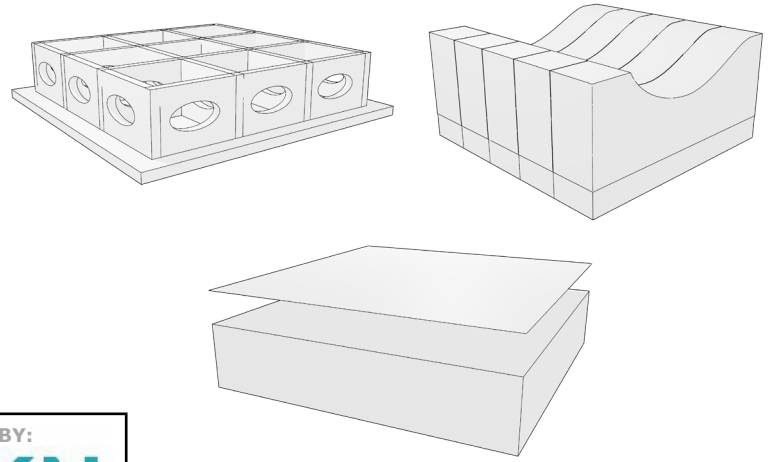
[2]



[1] https://www.fibreglast.com/blogs/learning-center/mould-construction-guide?srsltid=AfmBOopAWGzBOUfYhvynGlw5Er2tTEhXm2LF1KZufKC0qTo3GesVsuNw

REINFORCEMENT STRUCTURES





Functions:

- Support the tool
- Provide lifting points
- Allow for adjustment
- Airflow

Types of reinforcement:

- Eggcrate
- Frame

Material requirements:

- Ideally same or similar materials as face laminate to reduce distortion
- Should not be in contact with laminate face → about 2.5 mm (0.1 in.) gap should be in place (otherwise laminate will be distorted)

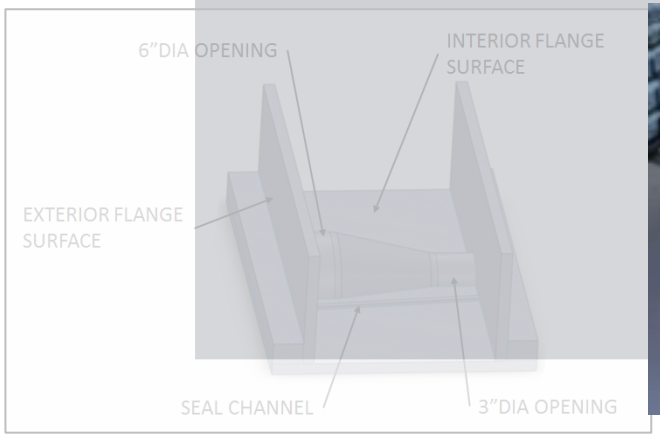
WORKFLOW OF COMPOSITE TOOL MAKING

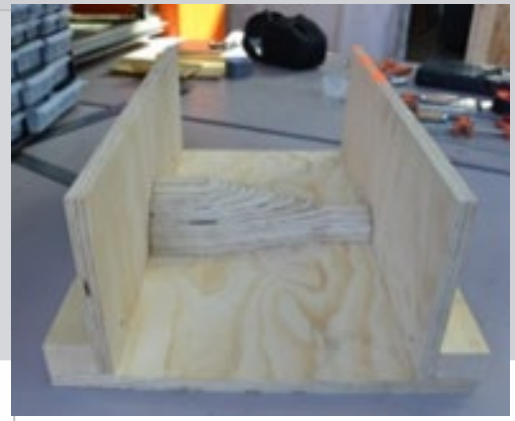
Design

Plug Fabrication

Tool Fabrication

Operation/ Maintenance





PLUGS

"A mould to make the mould"

Definition – Duplicate of the part to be produced, necessary for producing the mould contour

Use

- Define the totality of the shape, form, contour, and configuration of an object to be duplicated

Requirements

- Accurate dimensions – adjusted for shrinkage, distortion, and shape change
- Addresses draft angle and release directions
- Good surface finish

[1]

[2]

[1] https://explorecomposites.com/articles/tooling/using-mdf-for-composites-tooling/
[2] https://www.youtube.com/watch?v=YkFOqXs6-ac

TYPES OF PLUG CONSTRUCTION

Various constructions are possible:

- Solid block
- Base structure and skin
- With an existing part
  - CNC made part with surfacing skin
  - Skin applied on existing part (trim line)
- 3D printed plug
- Direct tooling (no plug)

[1]

[1] https://www.compositesworld.com/articles/tahoe-boats-t16-uses-3d-printed-tooling-from-thermwood

PLUG MATERIALS

Base Structure – should adhere well to tooling material, have smooth surface, and sufficient compressive strength

- Syntactic foam (polyurethane)
- Medium-density fibreboard (MDF)
- Tooling clay/plaster – fill cracks
- Sheet metal

Filler

- Pourable foams

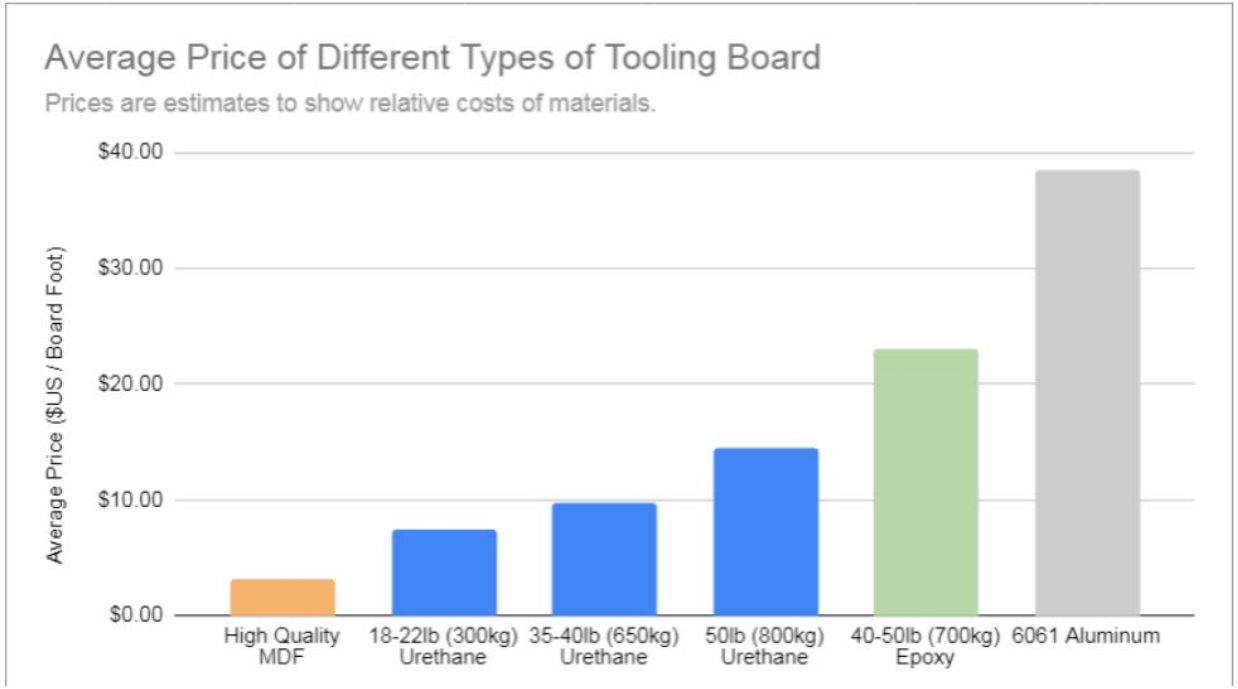
[1]

[1] https://www.youtube.com/watch?v=-Ia4n1XoVpw

TOOLING BOARD

- Tooling board
  - Polyurethane or epoxy – based
  - Uniform density → easy to CNC
  - Easy to sand/polish
  - Typically, more expensive than MDF
- MDF
  - Cheaper
  - Widely used for flat/simple shapes

[1]



[1] https://explorecomposites.com/articles/tooling/machinable-tooling-boards/

MODELING PASTE

- Suited for large applications or complex geometry that is difficult to make with tooling board
- High viscosity pastes (typically epoxy) can be extruded for thicknesses 10 – 50 mm (0.4 – 2.0 in.)
- Lower viscosities (typically urethane, vinyl ester, or polyester) sprayed in 2 – 8 mm (0.08 – 0.30 in.) per pass

[1]

[1] https://usa.sika.com/en/industry/tooling-composites/extrudable-epoxy-modeling-paste.html

CONSTRUCTING PLUGS

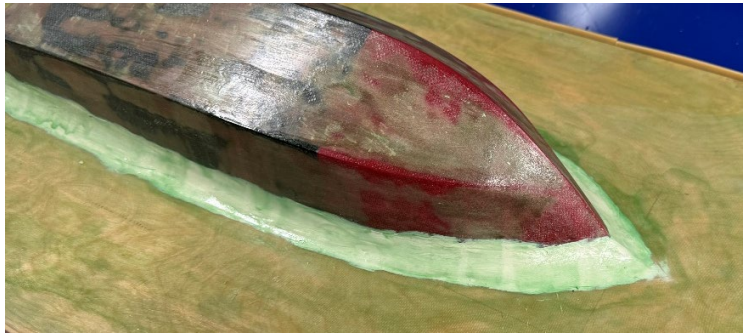
A method to build from plywood and pour foam:

- Block out the frame (lofting template) – wood, foam and sheet metal work well
- Fill frame with blocked out substrate (foams work well)
- Trim and sand (rasps and sanding blocks work well) to desired shape – do slowly in layers to avoid low spots

- A method to build from existing part:
  - Support structure can help locate and create features
  - Create flange along flange form – (clay/plasticine work well to fill gaps between flange and plug)

- Apply surface material

[1]



[1] https://www.youtube.com/watch?v=-Ia4n1XoVpw

PLUG SURFACING

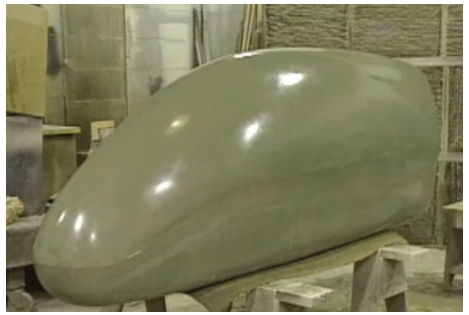
- Plug surface should be smooth, slick, and preserve structure
- Can add surfacing materials to improve properties
  - Fibreglass cloth/mat – strength
  - Primer (latex, epoxy) – fill porosity
  - Filler (autobody) – fill porosity
  - Gel coat

Works well with low density foam

Works well with tooling board

[1]

[1]



[2]

[1] https://www.youtube.com/watch?v=-Ia4n1XoVpw
[2] https://www.youtube.com/watch?v=WYZdfXaZtZE

PLUG SURFACING

- Plug surface should be smooth, slick, and preserve structure
- ‘Releasable surface’
- Can add surfacing materials to improve properties
  - Fibreglass cloth/mat – strength
  - Primer (latex, epoxy) – fill porosity
  - Filler (autobody) – fill porosity
  - Gel coat

Fibreglass cloth/mat – strength: Works well with low density foam

Primer (latex, epoxy) – fill porosity; Filler (autobody) – fill porosity; Gel coat: Works well with tooling board

[1]

[1]

[2]

[1] https://www.youtube.com/watch?v=-Ia4n1XoVpw
[2] https://www.youtube.com/watch?v=WYZdfXaZtZE

SEALING AND RELEASING MATERIALS

[1]

Mould Prep System

[2]

Release Wax

[3]

Release Agent

[4]

PVA

[1] https://chemtrend.com/brand/chemlease/
[2] https://fibertek.ca/products/partall%C2%AE-paste-2?srsltid=AfmBOooYOeZFkKYImA1xqLGgkXxCLr7cEL8j2wtl0VbuBTgiwURxlpPN
[3] https://www.henkel-adhesives.com/us/en/product/mold-release-agents/loctite_frekote_c-6001.html
[4] https://fibertek.ca/products/pva-poly-vinyl-alcohol-release?srsltid=AfmBOop0VzEIFm54DTmvXpvNPuUbhsJak5uX0-hzyKMEX01oaDjNIlbG

SURFACE FINISH

- Typically as smooth as possible to help with demoulding and reduce further finishing
  - Rougher surface increases mould-part adhesion
- Typically glossy, mirror-smooth finish
- If surface finish must be compromised, increase draft angle to help with demoulding

[1]

[1] https://www.youtube.com/watch?v=-Ia4n1XoVpw

WORKFLOW OF COMPOSITE TOOL MAKING

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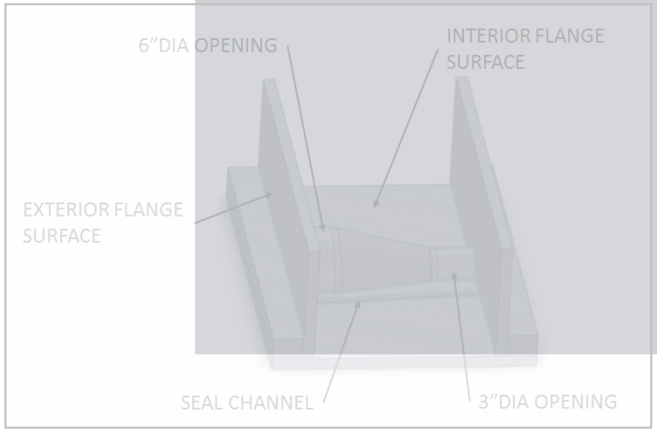
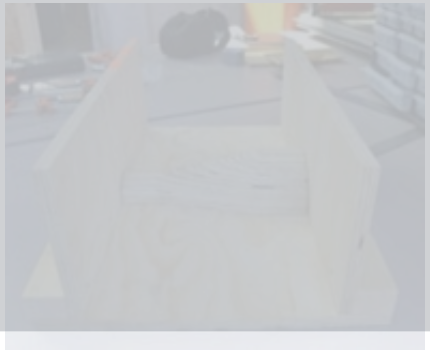
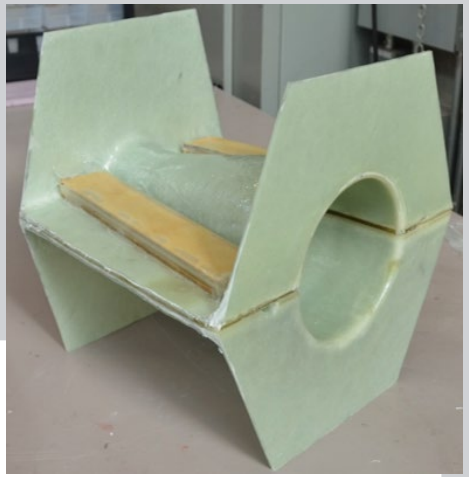
Tool Fabrication

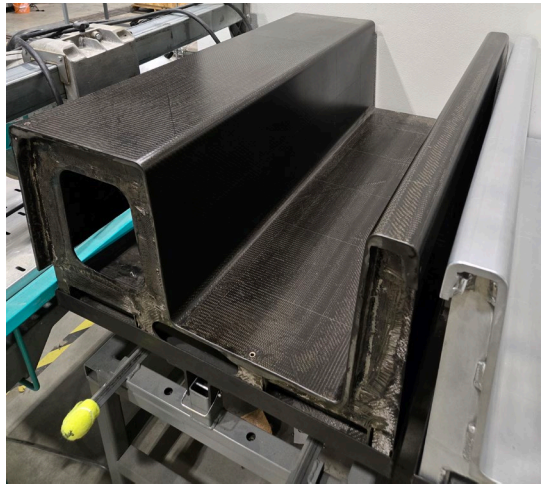
Operation/ Maintenance







TOOLING REINFORCEMENT



Carbon Fibre

Glass Fibre

Chopped Strand Mat

Fibre	Relative Weight	CTE Isotropy	Cost
Carbon Fibre	Low	Moderate	High
Glass Fibre	Low to moderate	High	Low to moderate

TOOLING FACE LAYUP

- Bulking material/agents – thickens resin, CTE properties
  - Glass mat/chopped strand mat (CSM)
  - Coremat laminate builder
  - Filled resin putty – glass microspheres, calcium carbonate
- Face laminate
  - Typically, randomly oriented pieces create quasi-isotropic laminate
- To reduce warping:
  - Tooling thickness is relatively thick (3-5x part thickness recommended) to reduce warping during curing
  - Typically, minimum of 6 mm (1/4 in.) face laminate thickness

Layup Schedule:

1	Woven glass fiber
2	CSM
3	CSM
4	Woven glass fiber
5	CSM
6	CSM
7	Woven glass fiber

TOOLING MATERIALS - RESINS

- Resin should be compatible with:
  - Tooling fibre material
  - Part material
  - Manufacturing process
  - Tooling gel coat
- Heat transfer
  - In-plane vs through thickness CTE

Typical Tooling Resins					
Resin	Mechanical Properties	Chemical Resistance	Dimensional Stability	Temperature	Cost
Epoxy	High	High	High	Moderate	High
Polyester	Low	Moderate	Low	Low	Low
Vinyl Ester	Moderate	High	Low	Moderate	Moderate

TOOLING MATERIALS – SURFACE COATING

[1]

- Gel coat (typically polyester) or surface coat (typically epoxy)
- The ‘moulding surface’ of the tool
- Applied to plug to provide smooth and fibre-free sanding surface
- Flexible, spray-on (ie. polyester tooling gel) or paint-on (epoxy) surface coat
- Should be compatible with tooling resin
- May be able to disregard gel coating for faster production times in single-use tooling at the cost of a compromised surface finish
- High temperature (eg. epoxy) face coats can hold shape for high temp. tooling
- Must be compatible with the resin used in the tooling

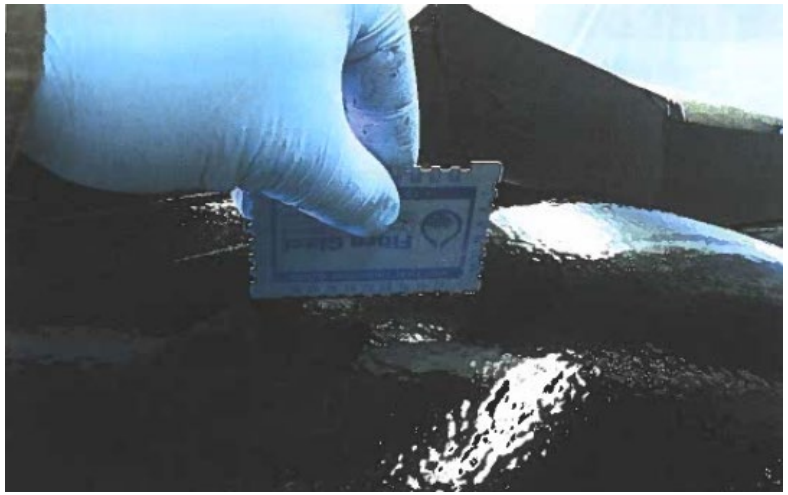
[1] https://fibertek.ca/products/white-waxed-gelcoat?srsltid=AfmBOorDbWsmQf8HXZA289th6BQdW7-jB3XNuXFxUPrCMZ0_A077u0Ii

APPLYING GEL COAT

- Gel coat is typically brushed or sprayed on (cup gun) in thin, even coats to avoid overheating during cure
  - Coating should not be too thick – generally 0.3 – 0.38 mm (0.012 – 0.015 in.)
  - Typically, 2 – 3 layers used –each layer is partially cured before applying subsequent layer
  - Gel coat gauge can show coating thickness
  - For sharp corners – brushing gel coat then spraying can help avoid puddling

[1]

[2]



[1] https://www.fibreglast.com/blogs/learning-center/chromaglast-paint-vs-gel-coat
[1] Wanberg, John. Composite Materials Fabrication Handbook #2

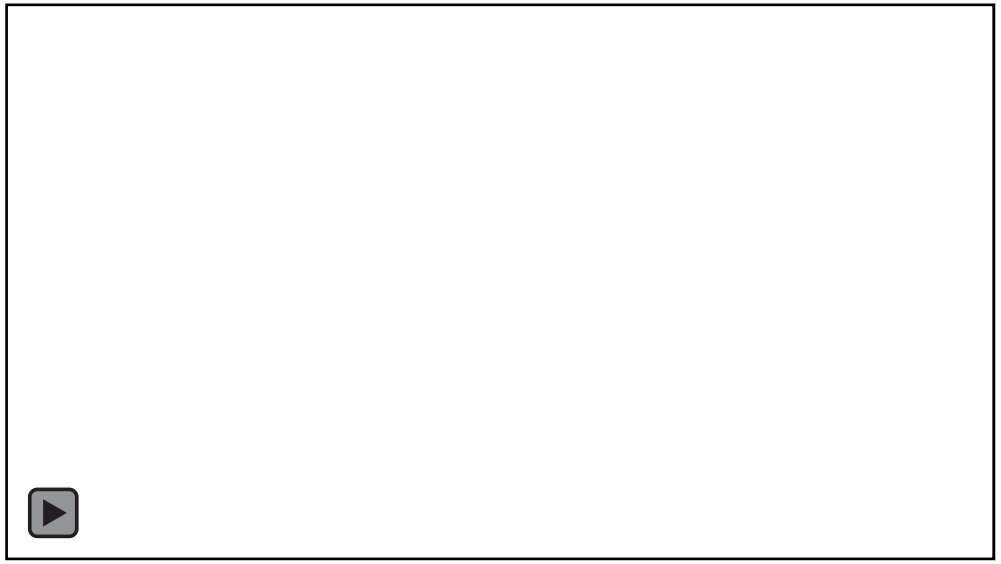
WHY ARE THE TOOLS ORANGE?

- Why are the tools orange?
  - Black layer applied first, then orange, then face sheet
  - Black layer appears when sanding too far
  - Pigmented, opaque resins help identify high and low spots easily

LAYUP TECHNIQUES

- Prepare plies slightly larger than finished dimensions – some fibres fray and drop during curing
- Plan resin, gel coat, and time necessary for layup schedule
  - Material and resin calculators are helpful
  - Account for cure times – often the rate limiting step
- For sharp corners:
  - Butt-up layers on either end
  - Overlap with a third layer
  - Cover all layers with a fourth layer

[1]

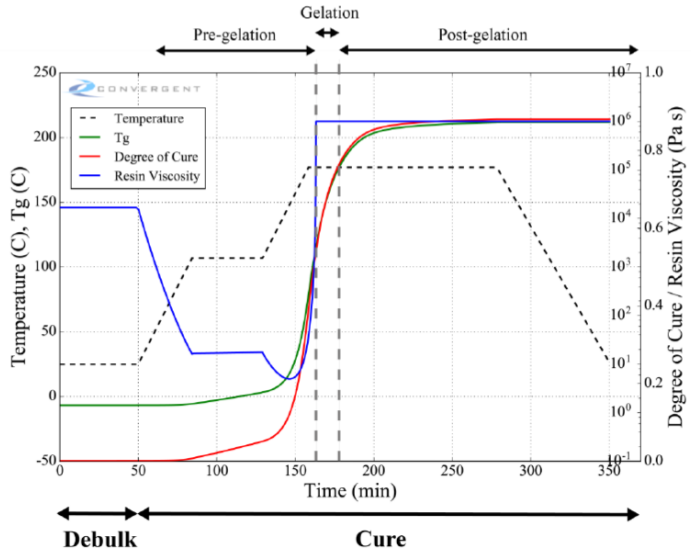


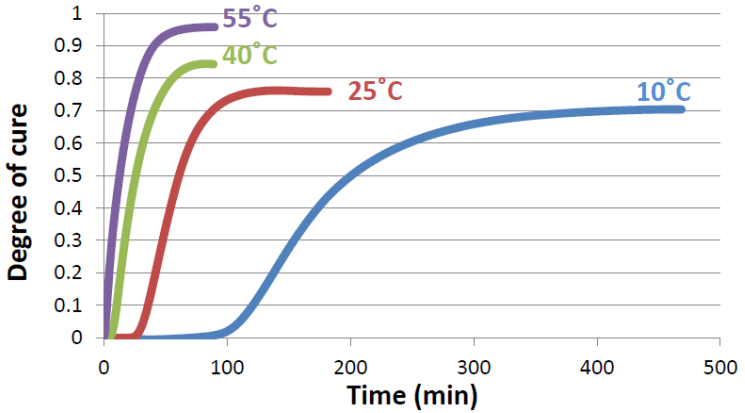
[1] Adapted from Wanberg, John. Composite Materials Fabrication Handbook #2

CURING

Considerations

- Highest degree of cure to obtain maximum Tg for a material
- For high temp. parts
  - Highest resin Tg
  - Cured at higher temperature than use temperature
- Cure times
  - For high CTE material → Low heat and maximum cure time recommended
  - Slower heating rate generally leads to less deformation



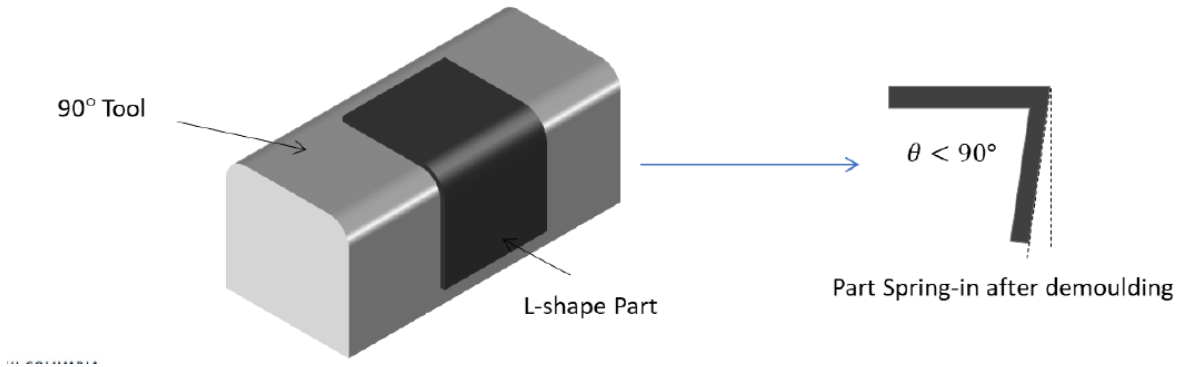


PROCESS INDUCED DEFECTS

Common issues

- Warpage
- Springback/spring-in

- Affected by
  - Layup
  - Reinforcement structure
  - Material - CTE and cure shrinkage mismatch
  - Tool-part interaction
  - Heat transfer
  - In-plane vs through thickness CTE



DEMOULDING

Materials:

- Plastic wedges
- Air nozzle and compressed air
- Rubber mallets
- Jigs/presses

Hand Removal Process:

1. For most materials, ensure full cure (no longer tacky/rubbery) to prevent deformation and/or sticking
2. Can use wedge between tooling and laminate and twist along the edge
3. Air nozzles can be put through voids formed with wedges – can lightly puff air until part is demoulded
4. Mallets and removal jigs can help remove difficult parts

[1]

[1] https://www.youtube.com/watch?v=4kyJP7TEtis

POST PROCESSING

- Trimming
  - With precision cutting tools (ie. Jigsaw, water-jet cutter, CNC router)
  - With hand tools
- Filing/wet-sanding – remove stray fibres
- Polishing
- Wash off release agents
- Secondary bonding

[1]

[1] https://www.youtube.com/watch?v=4kyJP7TEtis

Hand Tool	Part Size		Edge Diameter		
	Small Parts	Medium Parts	Straight	Small Diameter	Large Diameter
Hacksaw	☑	☒	☑	☒	☑
Bandsaw	☒	☑	☑	☒	☑
Rotary Tool (Abraisive Cut-off wheel)	☑	☒	☑	☒	☑
Rotary Tool (Rotary File)	☑	☒	☒	☑	☒

POLISHING

- Sand surface (up to at least 600 grit recommended) and polish → aiming for mirror-like finish
- Polish surface (typically at least 4 layers of release wax)
- Hand-held or machine polisher (some models can also be used for sanding)

[1]

[2]

[1] https://www.mirka.com/en-ca/know-how/applications/mould-preparation-and-polishing/
[2] https://fibertek.ca/products/aqua-buff%C2%AE-compounds-and-polish

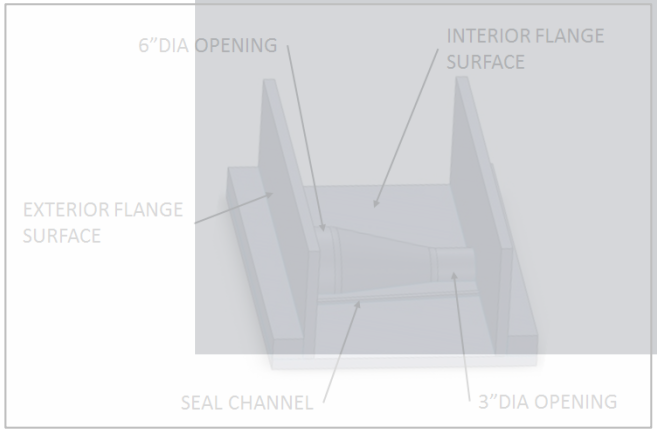
WORKFLOW OF COMPOSITE TOOL MAKING

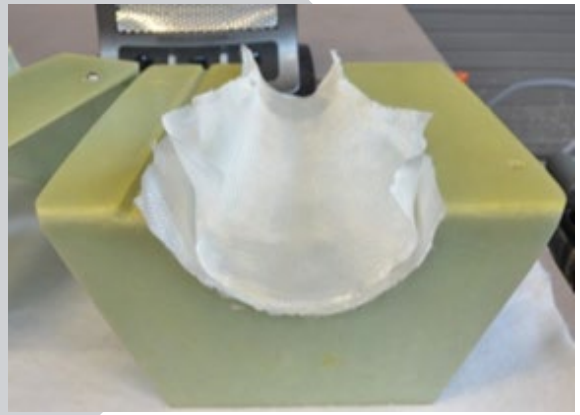
Design

Plug Fabrication

Tool Fabrication

Operation/ Maintenance

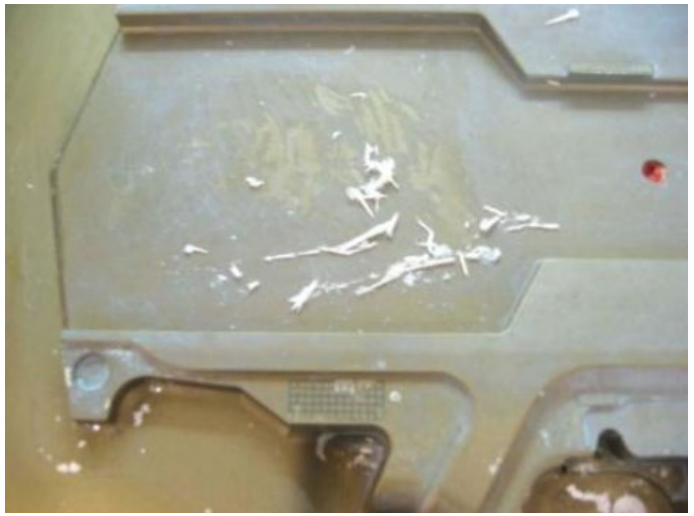




BETWEEN USES

- Solvent wiping – clean debris from tooling manufacture/usage
  - Soft cloths (microfibre) can be used to wipe access clay/wax residue
  - Can use acetone sparingly to further clean
- Check for damage between use (cracks, delamination, etc.) and repair
  - Filing/wet sanding to remove blemishes (180 → 600 grit)
  - Can fix pores by grinding out (rotary tool) and filling with epoxy surface coat or tooling gel coat
- If needed, touch up release agents

[1]



[1]

[1] https://axelplastics.com/sites/default/files/FO_%20ImportanceCleanMolds_12.pdf

REGULAR MAINTENANCE

- Periodic inspection and maintenance is process dependent
  - Visual inspection prior to each part, with more attention to areas with tight drafts
  - Preventative maintenance recommended (e.g. reapply release agents before sticking occurs)
  - Avoid buildup of release agents – can cause problems with heat transfer, aesthetics, dimensional properties
- Regular maintenance may include:
  - Sand and polish
  - Buff surface to restore smoothness
  - Stripping surface helps remove haze and wax residue buildup

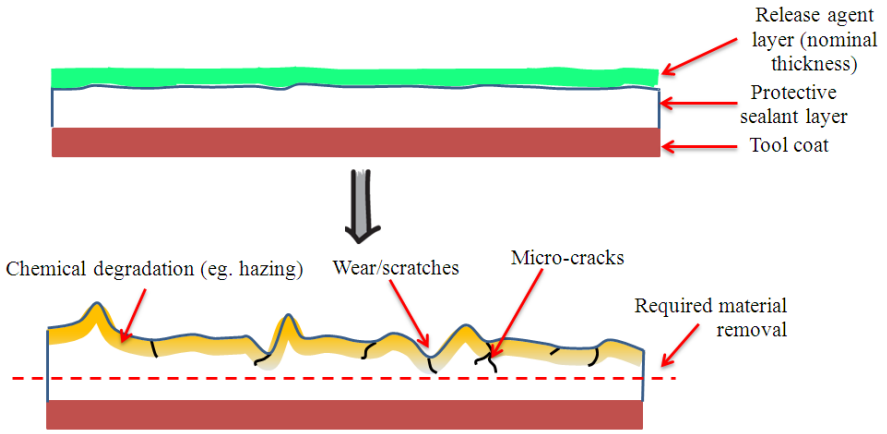
[1]

[2]

[1] https://chemtrend.com/brand/chemlease/
[2] https://www.amazon.ca/ENEACRO-7-Inch-Car-Polisher/dp/B08B8RZY73

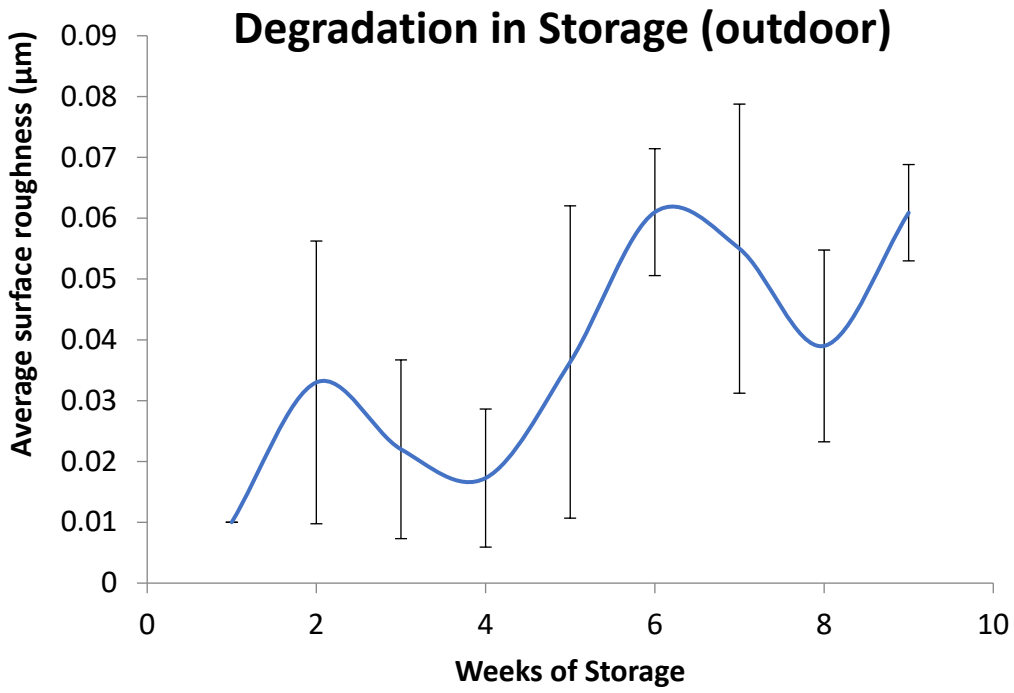
REPAIRING MOULDS

- Roughening, abrading, and cleaning recommended before repair
- Similar materials or formulation equivalent (similar CTE) to original material is recommended to fill holes/cracks
- Process typically involves the removal of damaged area (rotary tool), then built back up with fibre and resin, or just resin if appropriate
- Polishing and buffing typically performed to blend the surface



LONG TERM STORAGE

- Good to cover tooling surface to preserve quality
  - Reusable vacuum bags
  - Reject parts or 2-3 ply laminates ('splash')
- Recommended to avoid direct exposure to sunlight – most tooling materials can degrade
- Recessed or flushed tool edges can reduce failure during handling and storage
  - Supporting flanges or storing upright can avoid damage
  - Avoid resting on supporting ribs → may cause waves over time
- Recommended to apply wax coat before long term storage → easy removal of dust and debris



CONCLUSION

Composite tool construction workflow typically involves:

- ✓ Design (tool and plug)
- ✓ Plug fabrication
- ✓ Tool fabrication
- ✓ Use, maintenance and storage

Points to consider:

- ✓ MSTEP
- ✓ Various approaches exist
- ✓ Features, draft angle, flange
- ✓ Layup schedule
- ✓ Demoulding method
- ✓ Cure time for mould and part
- ✓ Storage
- ✓ Transportation method

Thank you for joining us!

Keep an eye out for upcoming AIM events:

An Introduction to Sheet Moulding Compound (SMC)

Presented by: Eric Martin, MESc

Fraunhofer Innovation Platform for Composites @ Western University

January 28th, 2026

https://compositeskn.org/KPC/A397

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/A396