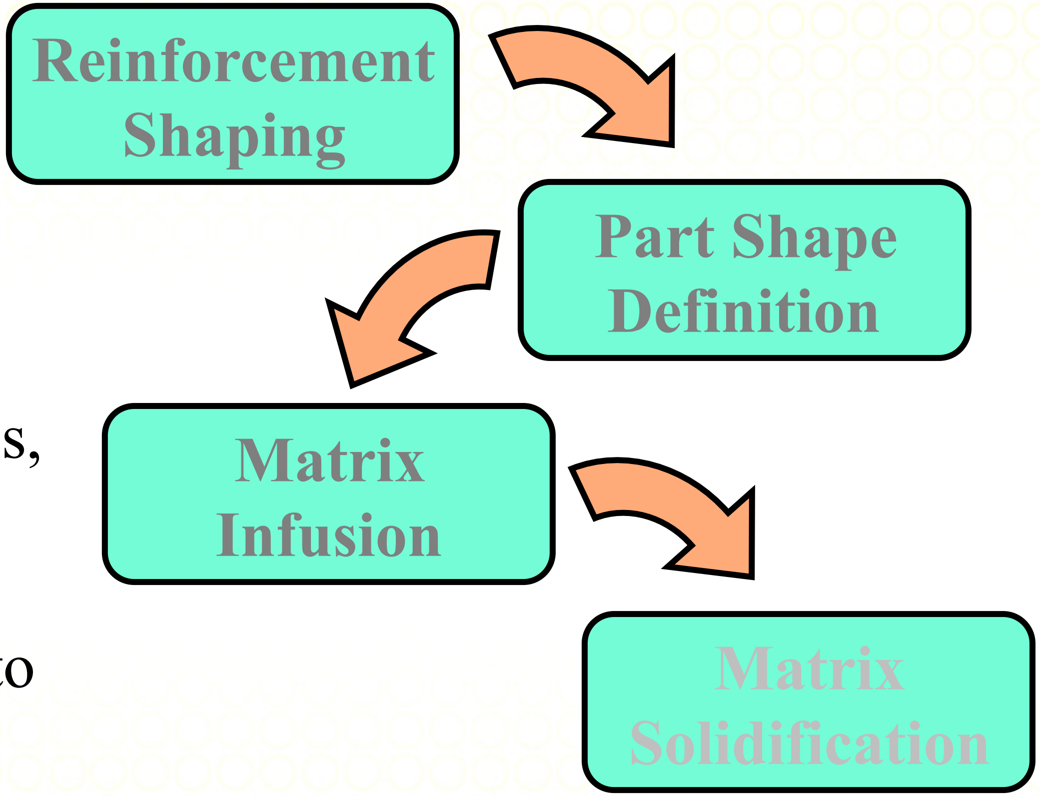
Polymer Composite Manufacturing Processes

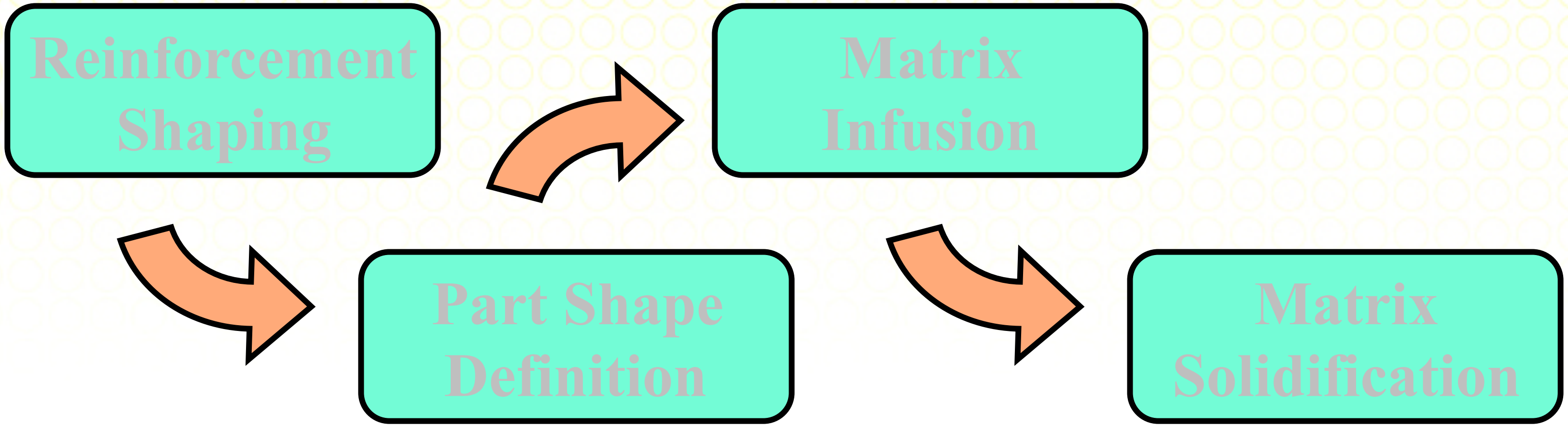
Introduction to Basic of Processing Techniques

A variety of processes are in use, some very well developed, others relatively new, being the focus of current research.

When considering each process, think about the equipment required, and what important process parameters may need to be specified.



Introduction



All processes can be *roughly* broken down into four important stages.

Batch Processes: Process stages **occur sequentially in time** to produce a single part

Continuous Processes:

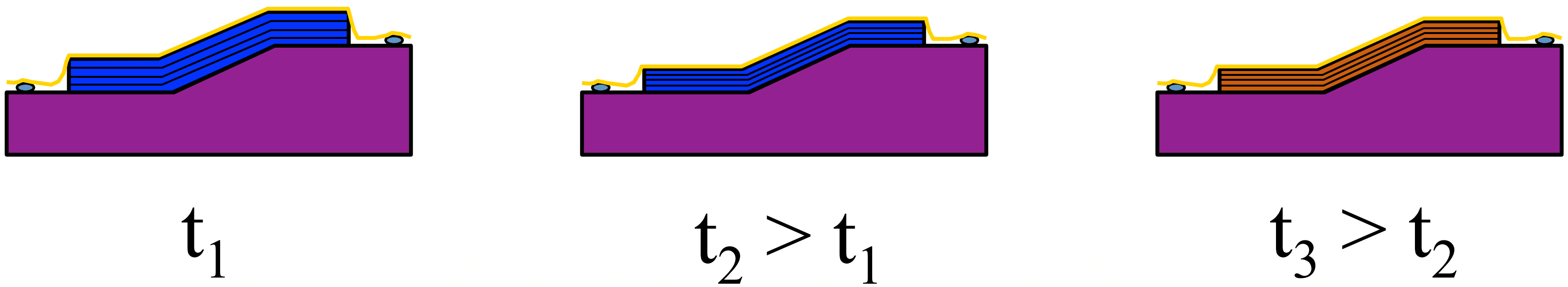
Product is **generated continuously**, passing through geographic stages

Batch Processes

The stages that make up such manufacturing processes occur **sequentially in time** to produce a **single part**.

These processes are usually completed on/in some form of mould.

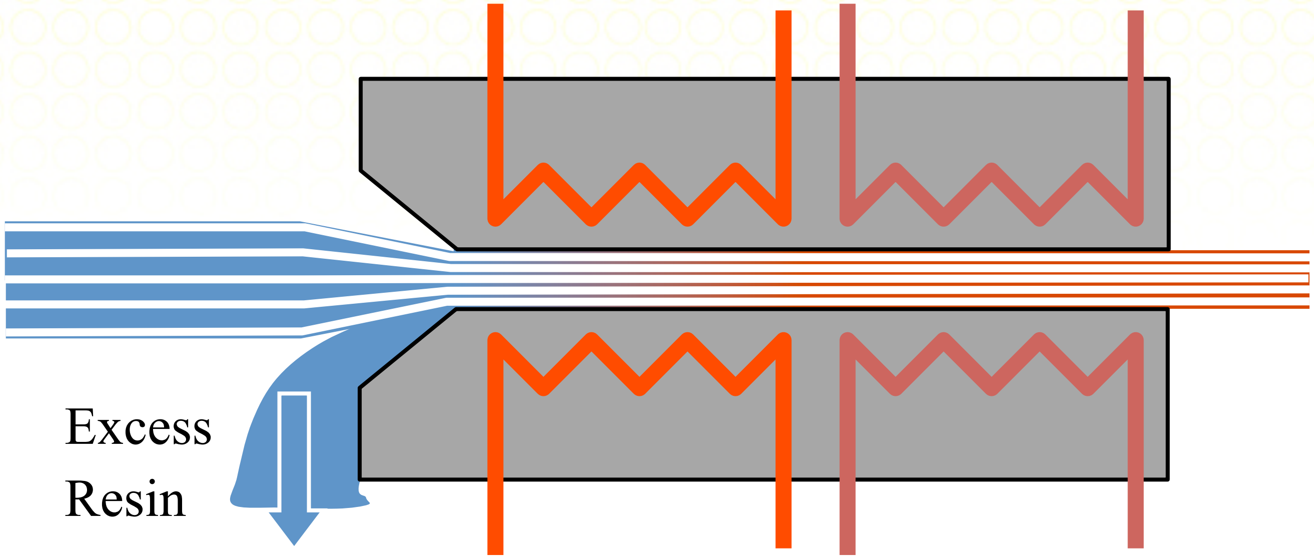
E.g.



For **batch processes**, one major goal of process design is to **reduce the cycle time** required to produce a part.

During such manufacturing processes, the product is **generated continuously**, formed as it passes through several geographic stages.

E.g.



For continuous processes, one major goal of process design is to achieve **increases in the process speed**.

Basic necessities for any process...

Reinforcement Shaping

- to define **initial** architecture of reinforcement.

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Part Shape Definition

- compressing reinforcement, or maybe prepreg, to **final** shape of the part.
- usually done within a **mould**, or **die**.

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Matrix Infusion

- to fully immerse the reinforcing fibres in the polymer matrix.
- should expel all air, or voids, from part.

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Matrix Solidification

- to provide for the necessary cure of a thermoset, or solidification of a thermoplastic.

Composites manufacturing processes are complex, and involve combinations of the following physical processes;

1) Reinforcement Shaping
2) Resin Infusion
3) Composite Consolidation
4) Heat Transfer within Composite
5) Thermoset Cure Reaction

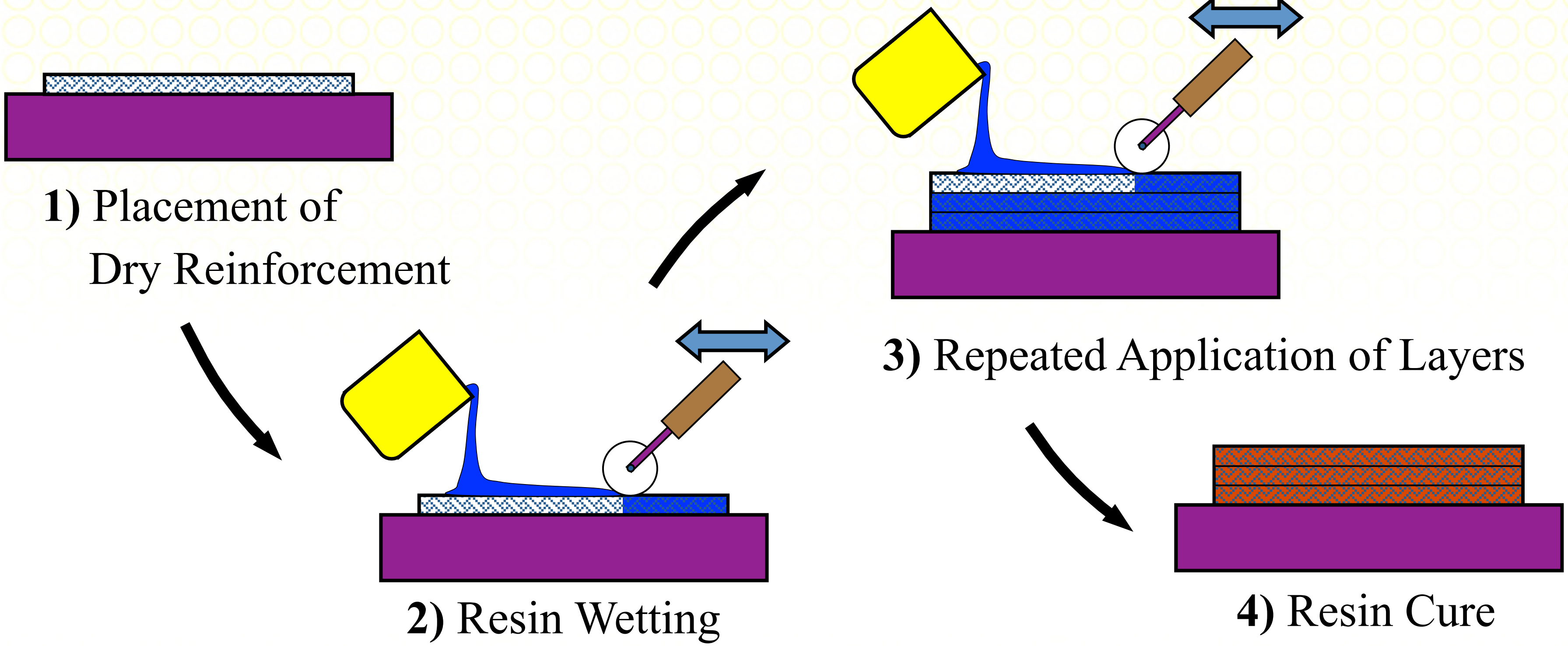
Why spend significant effort studying, and analysing them?

1) The full potential of many techniques are yet to be reached.

2) There is scope to produce parts:
   - Faster, Cheaper, and with higher Quality.

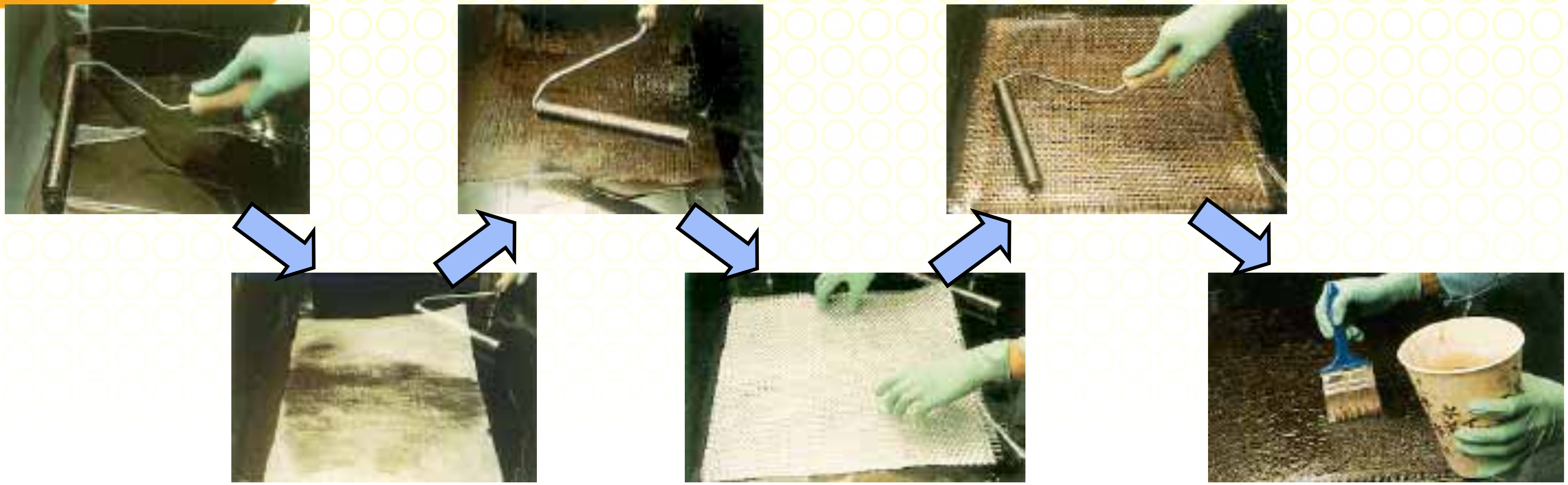
Process Description

Wet Hand Lay-up



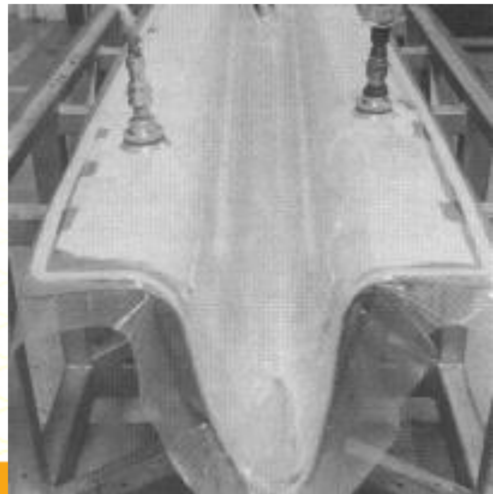
- Dry reinforcement and catalysed resin are draped over a one-sided mould.
- The resin is forced to impregnate the reinforcement using a roller.
- A number of layers can be built up in sequence.
- Resin cure is initiated, and the part removed when sufficiently rigid.

Wet Hand Lay-up

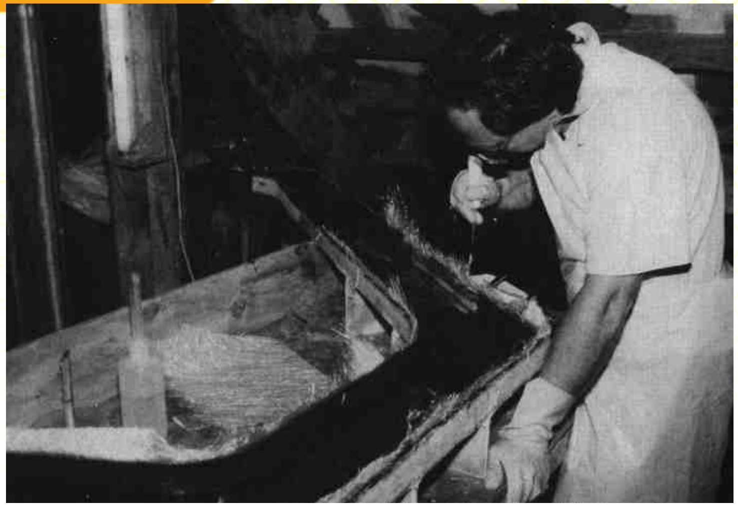


Part manufacture can be completed in several layers, with careful consideration of material compatibility, and sequential cure. Common modifications include:

Vacuum bagging after lay-up



Hand Lay-up



- Hand lay-up processes are very "hands on", and labour intensive. Typically applied to small production runs.
- With skilled operators, very good quality parts can be produced.
- Good control over applied reinforcement architecture.
- Possibility to reduce cycle time through careful design of the applied cure cycle.

Hand lay-up

- Advatages of Wet Lay-up
  - Tooling can consist of any material that will hold its shape under minimal pressure.
  - Tooling can be changed easily for engineering changes.
  - Investment in pressure devices such as press, autoclave, or vacuum pump is not required. The pump can improve the quality of parts.
  - Curing ovens are not needed

- Disadvantages of Wet Lay-up
  - Only addition-type cross-linking resin can be used, because condensation polymerization can cause bubbles and voids in part, which requires pressure.
  - Product is nonuniform and voids are common
  - Mechanical properties are low in comparison to other methods
  - Tight weave fabrics are difficult to saturate with high viscosity resins
  - Resin rich areas are common causing fracture points and shrinkage.
  - Only one finished surface

REINFORCING FIBER

- E-glass, S-glass, Aramid, Carbon/Graphite
- E-glass most common (process inherently produces lower "quality" composite laminate due to lack of tight resin content control and low compaction pressure)

- chopped mat material
  - consists of randomly oriented chopped fibers or swirled continuous fibers which are held together loosely by a binder

- woven fabric material form most common
  - available on rolls in widths from 36 in. to 60 in. typically

- unidirectional fabric
  - very fine filling (stitching) yarn

RESINS

- polyesters
- vinyl esters
- epoxies

MOLD/TOOL PREPARATION

- procedure to some degree dependent on:
  - tooling material
  - whether tool is being used in first cycle or subsequent cycle
- clean tool
  - wipe with a clean cloth dampened with solvent (i.e. Acetone)
- mold release agents
  - waxes
  - spray releases
  - release films
  - internal releases (added to gel coat or resin system)

APPLYING A MOLD RELEASE AGENT

- apply release agent
- allow period of time for release agent to "set up"
- Buff (polish) with clean cloth

THE WET LAY-UP PROCESS OFTEN BEGINS WITH A GEL COAT

- typically polyester, pigmented (different than mold colour), non-reinforced layer or coating
- produces decorative, high protective, glossy (shiny), coloured surface
- little or no additional finishing required
- can paint on, roll on, or spray on
- allow gel coat to set (gel)

CUTTING THE FABRIC

- cut desired pattern
- tools: shears and/or utility knife

WEIGHING OUT THE RESIN

- weigh out resin components in specified proportions to achieve desired resin content (desired fiber volume of finished part)
  - epoxy curing agents expressed in parts per hundred by weight (phr) of epoxy resin or parts by weight
    - EPON Resin 862/EPI-CURE 3274: 100/42
  - resin content expressed as percent by weight
    - epoxy resins typically 25% - 35% by weight (dependent on ability to wet out fiber, amount of resin bleeding out during cure, etc.)
    - need to account for process waste
      - resin bleeding out, remaining on brushes, ...
- draw quantity of resin components, in separate containers
- thoroughly mix resin components (combine resin into curing agent container)
- tools: containers, stirrers

RESIN SYSTEM QUANTITIES FOR THE DEMONSTRATION PART

- 16, 12 in x 12 in plies of 7781 E-glass cloth
- resin system is Shell EPON Resin 862/EPI-CURE 3274
  - (16 plies)(1 sq ft/ply)(1 sq yd/9 sq ft)(8.95 oz/sq yd)(1 lb/16 oz) = 0.994 lb
  - x/(x+0.994 lb) = 0.30 (x = lb of resin system)
  - x = 0.426 lb (193 gm) of resin system
  - EPON Resin 862 (100/(100 + 42))(0.426 lb) = 0.300 lb (136 gm)
  - EPI-CURE 3274 (42/(100 + 42))(0.426 lb) = 0.126 lb (57 gm)
  - account for process waste

APPLY RESIN TO FABRIC

- apply resin to fabric on mold surface or, preferably, wet out fabric with resin on separate surface and transfer to mold
- resin may be sprayed, poured or brushed on, and spread with brush and/or squeegee
- applying resin on mold surface prior to laying of fabric facilitates removal of entrapped air during compaction process - resin is forced up through the fabric along with the air
- tools: paint brush, spray equipment, squeegee

COMPACTION

- resin should be applied and compacted on mold surface from the center to the outside to facilitate removal of entrapped air, visually able to see air moving
- pressure can be applied with a squeegee and/or serrated roller
- bridging on female contours (radii) must be avoided
- tools: squeegee, serrated rollers

SPRAY-UP

WHAT IS SPRAY-UP?

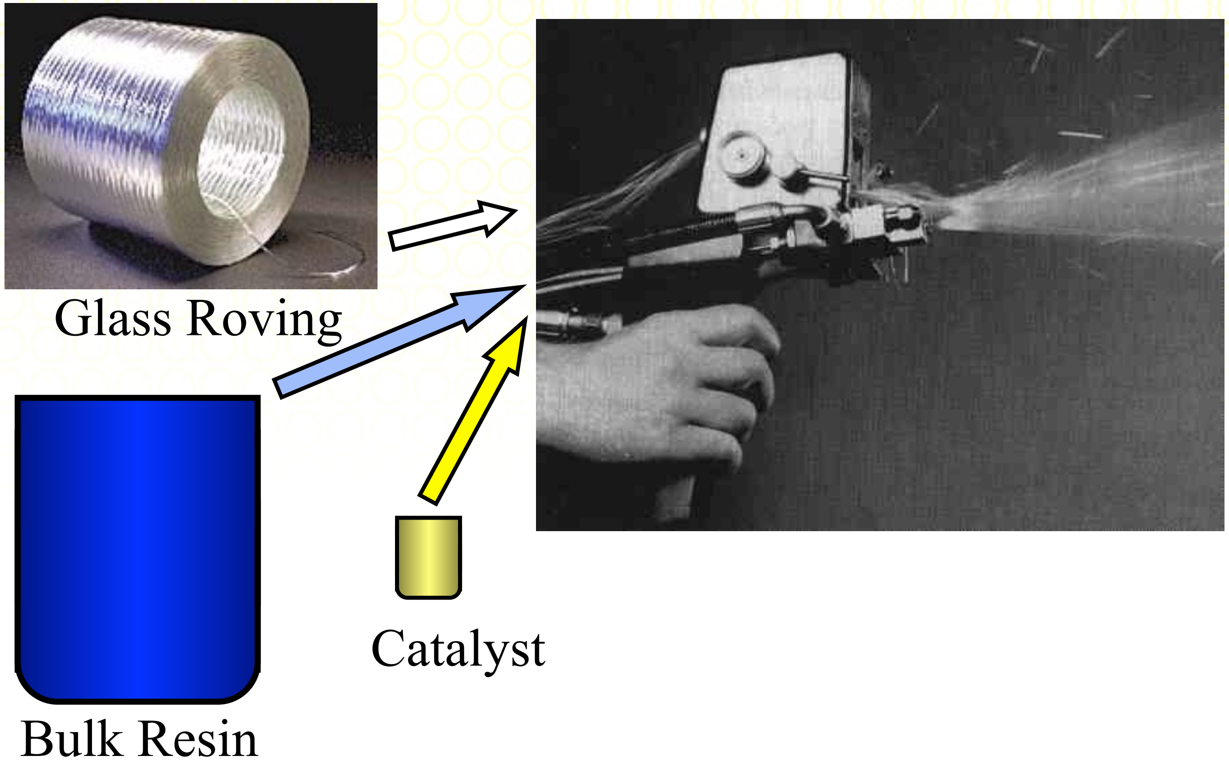
- one or more continuous fiber rovings fed through a chopper
- fiber rovings are cut to predetermined lengths
- chopped fibers are propelled into resin stream
- resin and chopped fibers are deposited simultaneously on mold
- rolled by hand with serrated rollers
- "automated wet lay-up" (however fibers not continuous)

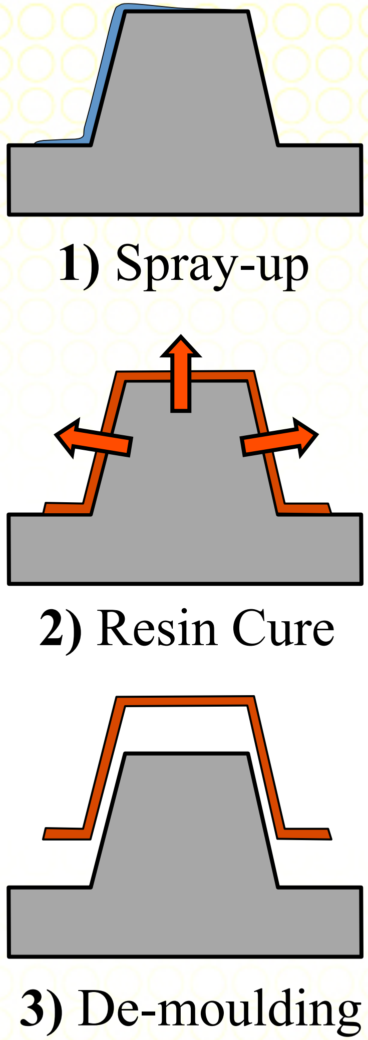
ADVANTAGES OF SPRAY-UP

- rapid lay-up
- ability to fabricate large, complex shapes where forming and fitting of mat or fabric would be difficult

Spray-up

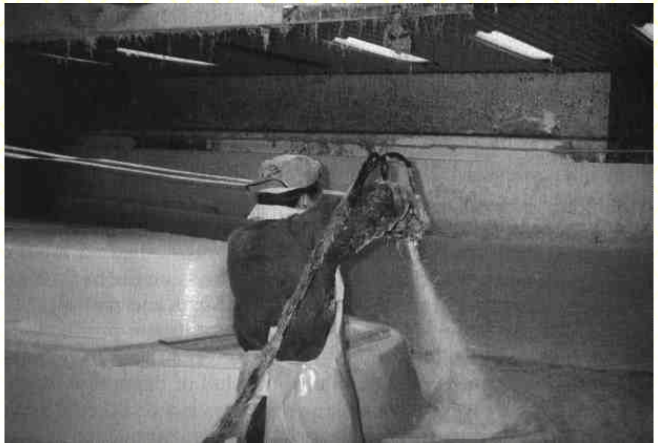
Process Description

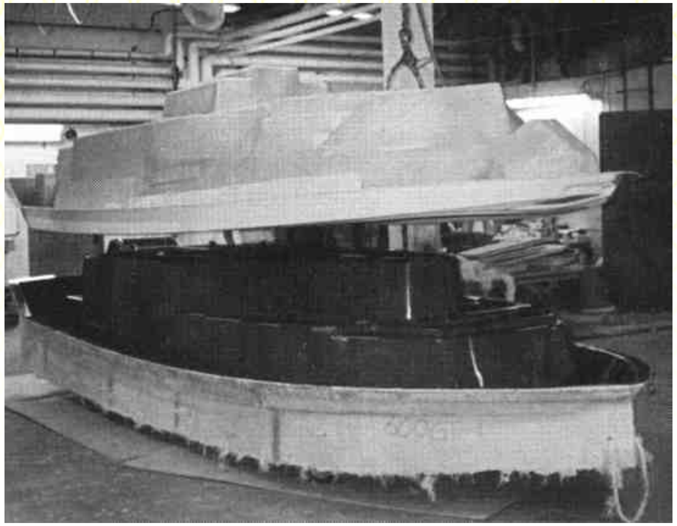


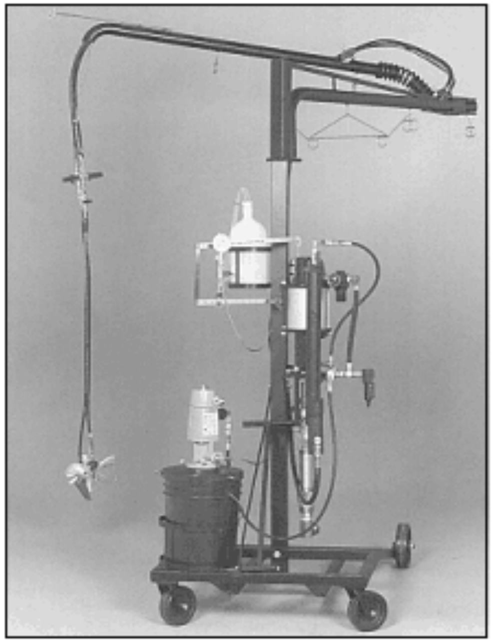


- Glass roving, bulk resin and catalyst are fed to the spray gun.
- The mixture is sprayed over a mould, defining part shape.
- Resin cure is initiated, and the part removed when rigid.

Spray-up


Part being sprayed-up


Part removed from mould.


Full dispensing system

Chopper

Roving

Atomised resin and catalyst

Spray-up

• Relatively fast, and simple method for applying reinforcement and matrix to a mould, in one step.

• Moderate equipment expense.

• Limited to random chopped fibre architecture (limits structural properties).

• Must be careful to maintain a clean, and healthy working environment.

• Improvements to application procedure affected through gun settings, and by experience and skill of operators.

• Opportunities to reduce cycle time through careful design of the cure cycle.

REINFORCING FIBER AND RESIN SYSTEM

- E-glass roving
- polyester resin
  - base resin (includes crosslinking agent, usually styrene)
  - catalyst (initiator)
  - accelerator

SPRAY-UP SYSTEM COMPONENTS

- pumps for resin and/or catalyst
- pressure pots for catalysts
- pressure pots for flushing solvents
- chopper for fiber reinforcement
- various air regulators and gauges for control
- various hoses for transporting materials
- gun assembly for dispersing materials
- compressed air source

RESIN SYSTEM MIXING METHODS

- external mix
  - resin/catalyst
  - resin and catalyst/resin and accelerator (two-pot system)
- internal mix
  - resin/catalyst (catalyst injection)
- air-atomized - addition of air into the gun to disperse resin mix
- hydraulic pressure to disperse resin mix

CHOPPERS

- chops continuous fiber roving in lengths typically 1.5 - 5 mm.
- driven by small air motor, speed can be controlled by valves
- chopper comprised of two rollers
  - one made of rubber or urethane (cott wheel)
  - one made of aluminum with fitted slots to hold razor blades (cutter wheel)
  - air motor drives either wheel with the roving passing between the two wheels

FABRICATION PROCESS

- if gel coat spray thin pass of resin (no chopped roving)
- usually start spray passes at bottom of mold using horizontal spray pattern
- overlap about one-third to assure uniform layer
- follow horizontal layer with vertical layer, if possible (will yield best uniform laminate)
- gun head 18 - 24 in from the mold surface
- most outputs and operators maintain 0.050 in nominal thickness per pass

ADDITIONAL PROCESSING IS NEEDED AFTER CHOP IS APPLIED TO MOLD

- best laminate - one pass, roll out, let gel, continue
- rolled by hand with serrated rollers (aluminum or plastic) to remove air, compact the fibers and smooth the surface
- start rolling near center and work to edges
- male molds easier to spray-up and roll out, however usually more fiber and resin overspray (waste) on floor
- cure will be similar to wet lay-up