Vacuum Bagging / Autoclave

ver 1

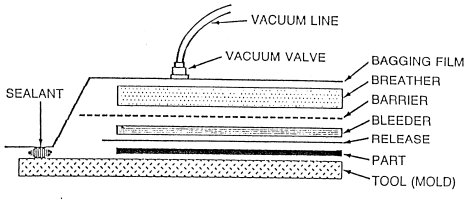
Autoclave Process Sequence

High Performance Parts

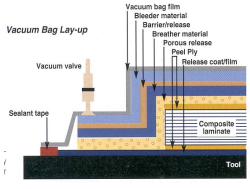
- Prepare plies
- Stack plies in tool
- Add dry material to absorb excess resin & remove volatiles
- Apply vacuum bag & cure in autoclave
- Oven postcure for environmental durability
- Trim
- Inspect
- Assemble

Hand lay-up shop

Vacuum Bag Assembly



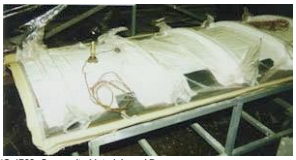
Vacuum bag



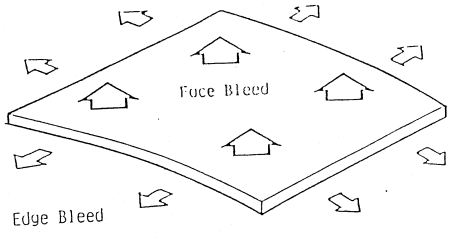
Lay-up

Material on stiffening structure

Vacuum bag and fittings attached



Alternate Resin Bleed Paths



Release Materials

- Common Materials:
  - Fiberglass:
    - Coated with Teflon
    - Coated with Mold Release
  - Nylon
  - Polyester
  - Film

Breather Material

- Common Materials
  - Fiberglass
  - Polyester Felt
  - Cotton
- Limitations
  - Pressure
  - Temperature
- Failure Modes
  - Inadequate Testing
  - Quality

Sealant Tape

- Major Manufacturers
  - Schnee-Morehead
  - General Sealants
- Limitations
  - Tack
  - Temperature
- Failure Methods
  - Release
  - Flow

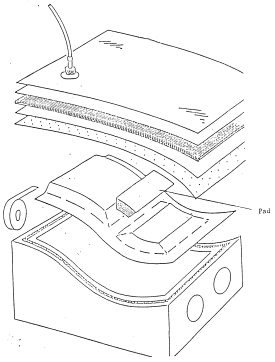
Nylon Films

- Manufacturing Methods
  - Cast
  - Blown
- Film Types and Properties
  - Resin Types - 6 - 66 - 666
  - Sheets, Tubes, & Bags
- Limitations
- Failure Methods

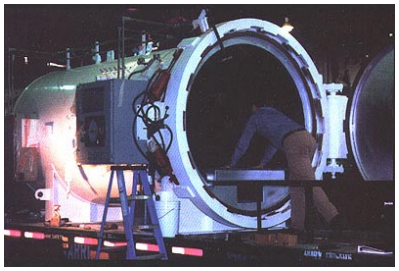
Vacuum Bagging Problems

- Labor Intensive
- Inconsistent Performance
- Trapped Air/Volatiles
- Controlling Bleed
- Poor Heat Transfer
- Consumes Expensive Materials
- Wrinkles
- Loss of Seal
- Inadequate Pressure Transmission

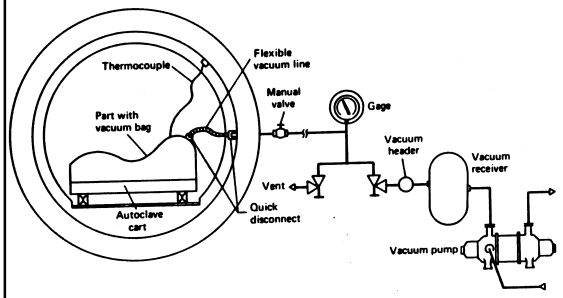
Use of Rubber Pad to Prevent Bridging



Autoclave



Autoclave



Autoclave Features

- Gases
  - Air (If T < 150ºC)
  - N_2 (most common)
  - CO_2 (if P < 300 psig)
- Heating
  - Electric (if small)
  - Indirect gas fired (if large)
  - Integrally heated tooling (recently)
- Gas Circulation
  - Needed for heat transfer
  - Velocity = 1 to 3 m/s
- Vacuum
  - One outlet per 2.5 ft^3 of bag area
  - Trap volatiles (may be toxic)
  - Control internal bag pressure (hard!)

Epoxy Autoclave Cure Cycle

- Apply vacuum inside bag at 20-30" Hg (70-100 kPa
- Apply autoclave pressure at 85 ± 5 psi (585 ± 35 kPa
- Heat slowly to 250 ± 10ºF (120 ± 5ºC) at 3 to 5ºF/min (2 to 3ºC/min)
- Hold at T and P 60 to 70 min
- Raise P to 100 ± 5 psi (690 ± 35 kPa)
- Release vacuum
- Raise T to 350 ± 10ºF (177 ± 5ºC) at 3 to 5ºF/min (2 to 3ºC/min)
- Hold at T and P 120 ± 10 min
- Cool slowly to below 100ºF (40ºC) at 5ºF/min (3ºC/min)
- Release autoclave pressure

Alternative Curve Cycle for V-378A

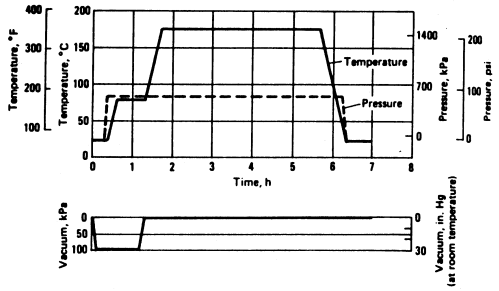


Fig. 2 Alternate cure cycle for V-378A. Event sequence: apply full vacuum and 586 kPa (85 psi) pressure; heat to 80 °C (180 °F) at ≤3 °C (5 °F)/min; hold at 80 °C (180 °F) for 35 min, then vent; heat to 175 °C (350 °F) at ≤3 °C (5 °F)/min; hold at 175 °C (350 °F) for 4 h; cool at ≤3 °C (5 °F)/min to room temperature, then release pressure; postcure at 245 °C (475 °F) for 4 h

Large Autoclave Example

D = 25 ft
L = 60 ft
T < 650°F (insulated on inside)
Steel design stress = S = 13,700 psi
P = 300 psig

Design equation for thickness

$$t = \frac{Pr_i}{SEj - 0.6P} + C_c$$

↑ corrosion allowance, $\frac{1}{8}$"

↑ joint efficeincy, 0.85

t = 4" thick
Steel volume = πDLt = 1,590 ft^3

Steel Weight = ρV = 7.85(62.4) (1,590) = 780,000 lbs (Cylinder only)

Total steel ~ 1 million lbs > $1 million

Maximum plane area = 23 x 58 ~ 1,300 ft^2

Volume of autoclave = 29,440 ft^3 (220,000 gallons)

Autoclave Curing Evaluation

- Investment
  - Autoclave system expensive
  - Modest tooling
- Materials
  - Thermoset advanced composites tailored for autoclaves
- Products
  - Low volume
  - Moderate areas (some exceptions)
  - Complex shapes
  - High cost
- Processing
  - Slow
  - Low Labor (excluding preparation)
  - Remote Hazards
- Quality
  - Low defects
  - High properties
  - Fair consistency