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UAB

Process Simulation Long Fiber Thermoplastic Polypropylene Bus Seat Component

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Objectives

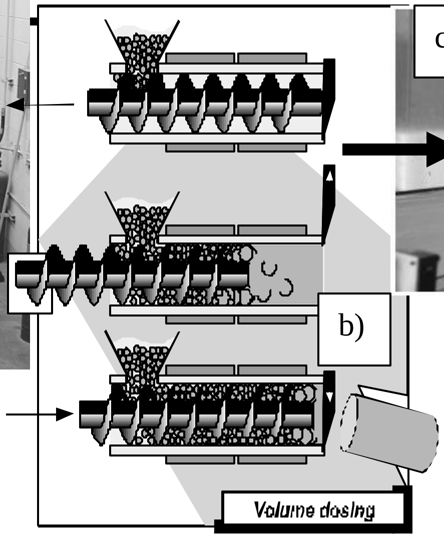
- To design and analyze components of transportation vehicles with a goal of cost and weight savings; Ex. Bus Seat
- To conduct process simulation studies

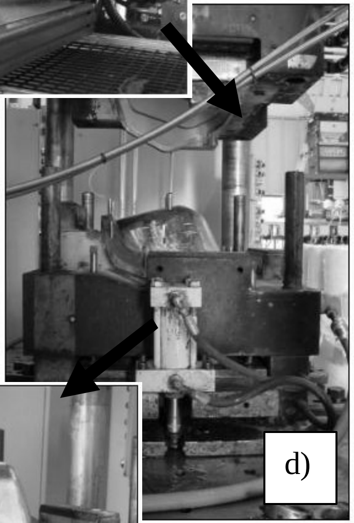
Long Fiber Thermoplastics

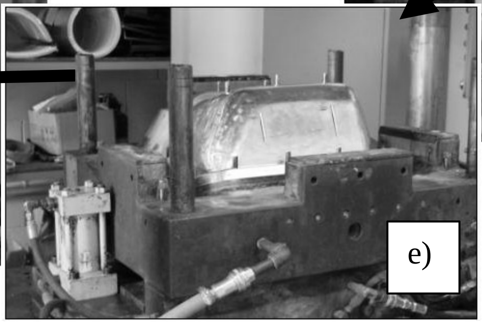
Long-Fiber Thermoplastic (LFT) materials are a family of compounds that incorporate fibrous fillers into a wide variety of crystalline and amorphous thermoplastic resins. LFT materials provide the following advantages over unreinforced and short fiber reinforced thermoplastics:

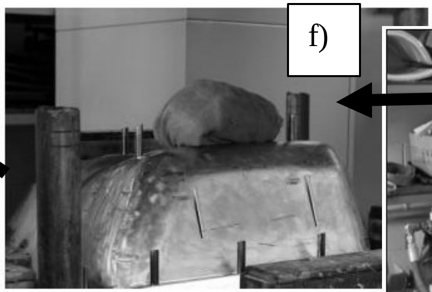
- Superior mechanical properties
- Higher notched impact strength
- Reduced tendency to creep
- Stability at elevated temperature and humidity conditions

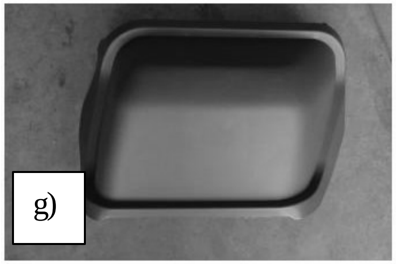
Production Cycle of LFT Part











Steps in Extrusion / Compression Molding : a) Plasticator, b) Twin Screw action, c) Charge exiting from plasticator,
d,e) Compression Mold with Engine Tool, f) Charge Placement, g) Finished Part.

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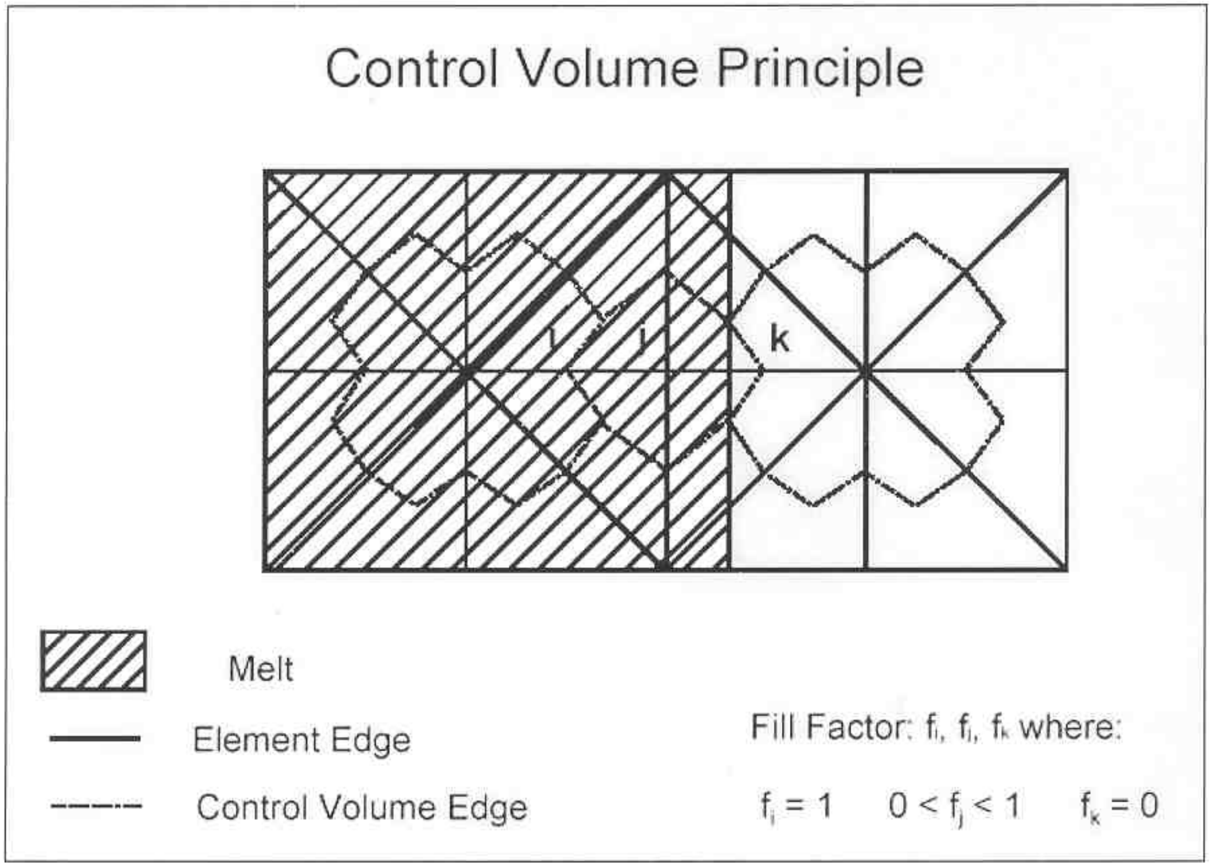
Advantages of Process Simulation

- Proof of Concept
- Shorter Development Times
- Higher Quality Parts
- Avoidance of Tool Modifications
- Shorter Tool Setup Times

Process Simulation

- Flow Simulation
- Heat Transfer Simulation
- Fiber Orientation
- Anisotropic Elastic Properties
- Thermomechanical Theory

Flow Simulation



Flow Simulation

Isothermal

$$\frac{\partial}{\partial x}\left[S\frac{\partial p}{\partial x}\right]+\frac{\partial}{\partial y}\left[S\frac{\partial p}{\partial y}\right]-\dot{h}=0$$

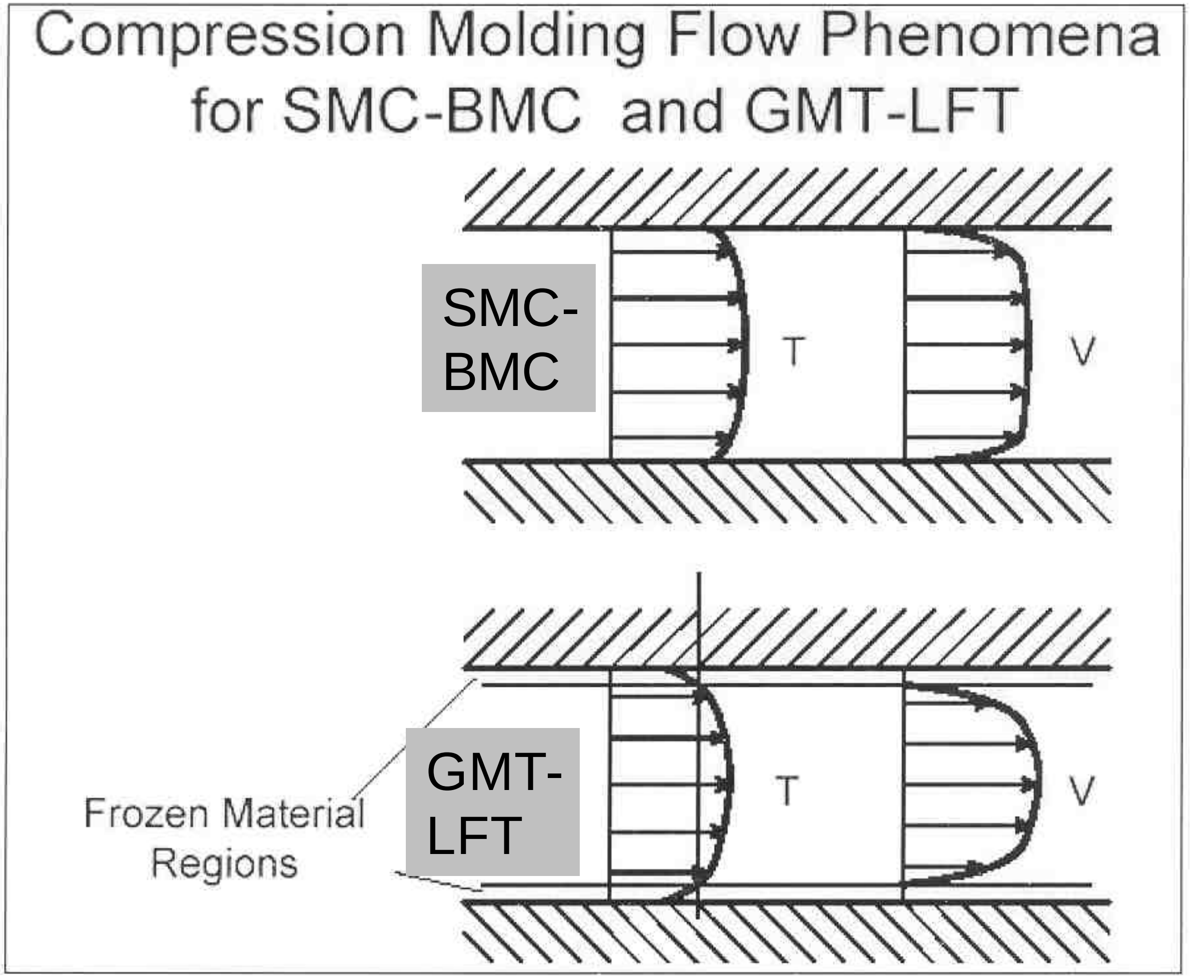
$$S=\frac{h^3}{12h}$$

Flow Channel Height

Viscosity

Flow Conductivity

SMC Vs LFT Processing



Flow Simulation

Non-Isothermal

$$h = \frac{P_1 a_T}{\left(1 + a_T P_2 \left|\dot{g}\right|\right)^{P_3}}$$

$$\log(a_T) = \frac{8.86(T_B - T_S)}{101.6^0 C + (T_B - T_s)} - \frac{8.86(T - T_S}{101.6^0 C + (T - T_s)}$$

Heat Transfer Simulation

Energy Transport During Filling Stage

$$r c_p \frac{\partial T}{\partial t} = l \frac{\partial^2 T}{\partial z^2} \qquad \text{Conduction}$$

$$- r c_p \left(n_x \frac{\partial T}{\partial x} + n_y \frac{\partial T}{\partial y} \right) \qquad \text{Convection}$$

$$- t_{xz} \frac{\partial n_x}{\partial z} - t_{yz} \frac{\partial n_y}{\partial z} \qquad \text{Diffusion}$$

Heat Transfer Simulation

Rate of Heat Generation

$$\dot{Q}_{S,k} = Q_g \frac{\partial c_{S,k}}{\partial t}$$

Temperature Dependency of the Rate of Cure

$$\frac{\partial c_{S,k}}{\partial t} = f(c_{s,k}, T) = (d_1 + d_2 c^m{}_{s,k})(1 - c_{s,k})^n$$

$$d_1 = a_1 e^{-b_1 / RT_k}$$

$$d_2 = a_2 e^{-b_2 / RT_k}$$

Fiber Orientation

Jeffrey Model for Fiber Rotation

$$\frac{\partial f}{\partial t} = \frac{{r_e}^2}{{r_e}^2+1}(\sin f \cos f (n_{y,y} - n_{x,x}) + \cos^2 f n_{y,x} - \sin^2 f n_{x,y})$$

$$-\frac{1}{{r_e}^2+1}(\sin f \cos f (n_{y,y} - n_{x,x}) - \sin^2 f n_{y,x} + \cos^2 f n_{x,y})$$

Fiber Distribution Function

$$\frac{dy}{dt} = \frac{\partial y}{\partial t} + n_x \frac{\partial y}{\partial x} + n_y \frac{\partial y}{\partial y} = -\frac{\partial (y \dot{f})}{\partial f}$$

Fiber Orientation

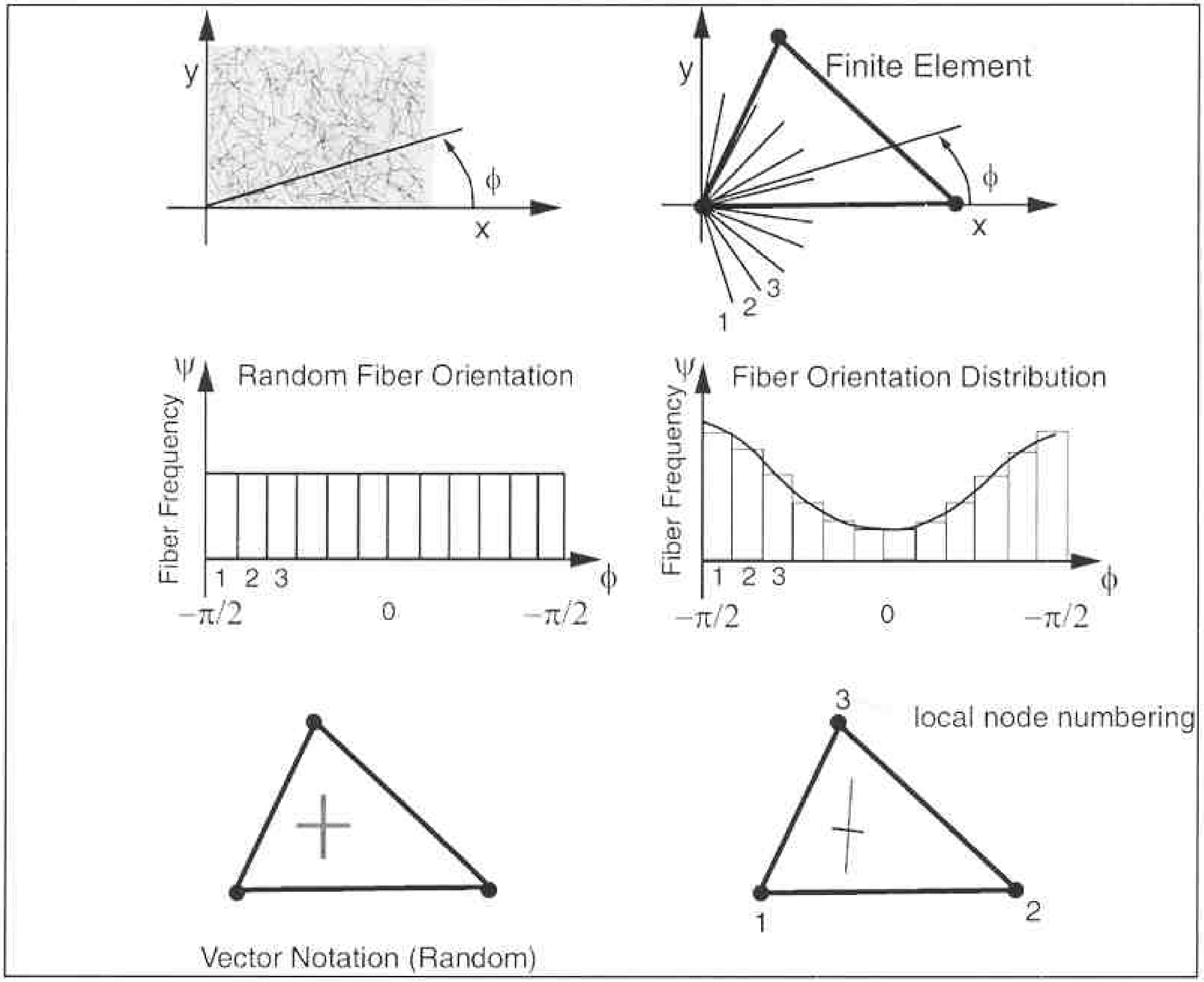
Folger-Tucker Model

$$\frac{\partial f}{\partial t} = -C_I \dot{g} \frac{1}{y} \frac{\partial y}{\partial f} - \sin f \cos f n_{x,x} - \sin^2 f n_{x,y} + \cos^2 f n_{y,x} + \sin f \cos f n_{y,y}$$

$$\dot{g} = \sqrt{2n^2{}_{x,x} + (n_{x,y} + n_{y,x})^2 + 2n^2{}_{y,y}}$$

$$\frac{\partial y}{\partial t} = C_I \dot{g} \frac{\partial^2 y}{\partial f^2} - \frac{\partial}{\partial f}\left[\begin{array}{l} y\,(-\sin f \cos f n_{x,x} - \sin^2 f n_{x,y} + \\ \cos^2 f n_{y,x} + \sin f \cos f n_{y,y}) \end{array} \right]$$

Fiber Orientation



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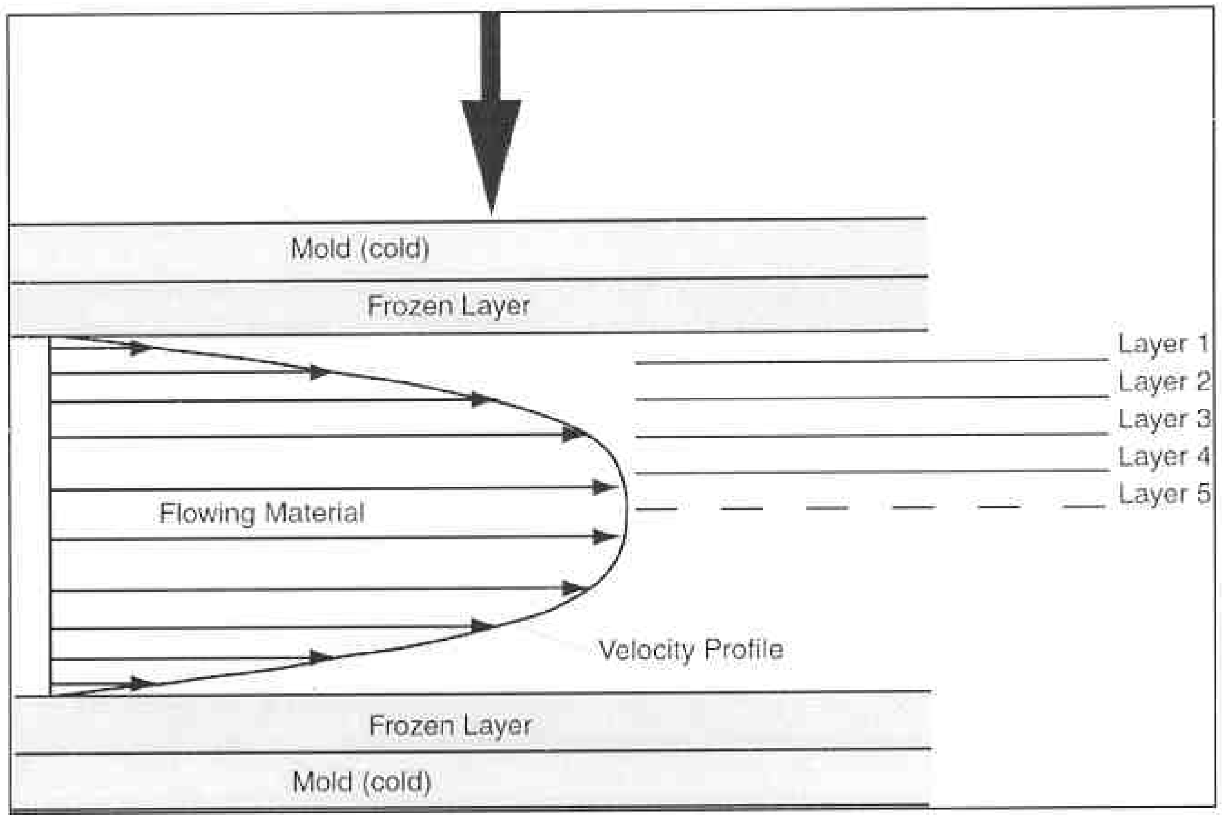
Velocity Profile During Compression Molding



Fibers become fixed in the regions close to the mold walls as the material freezes

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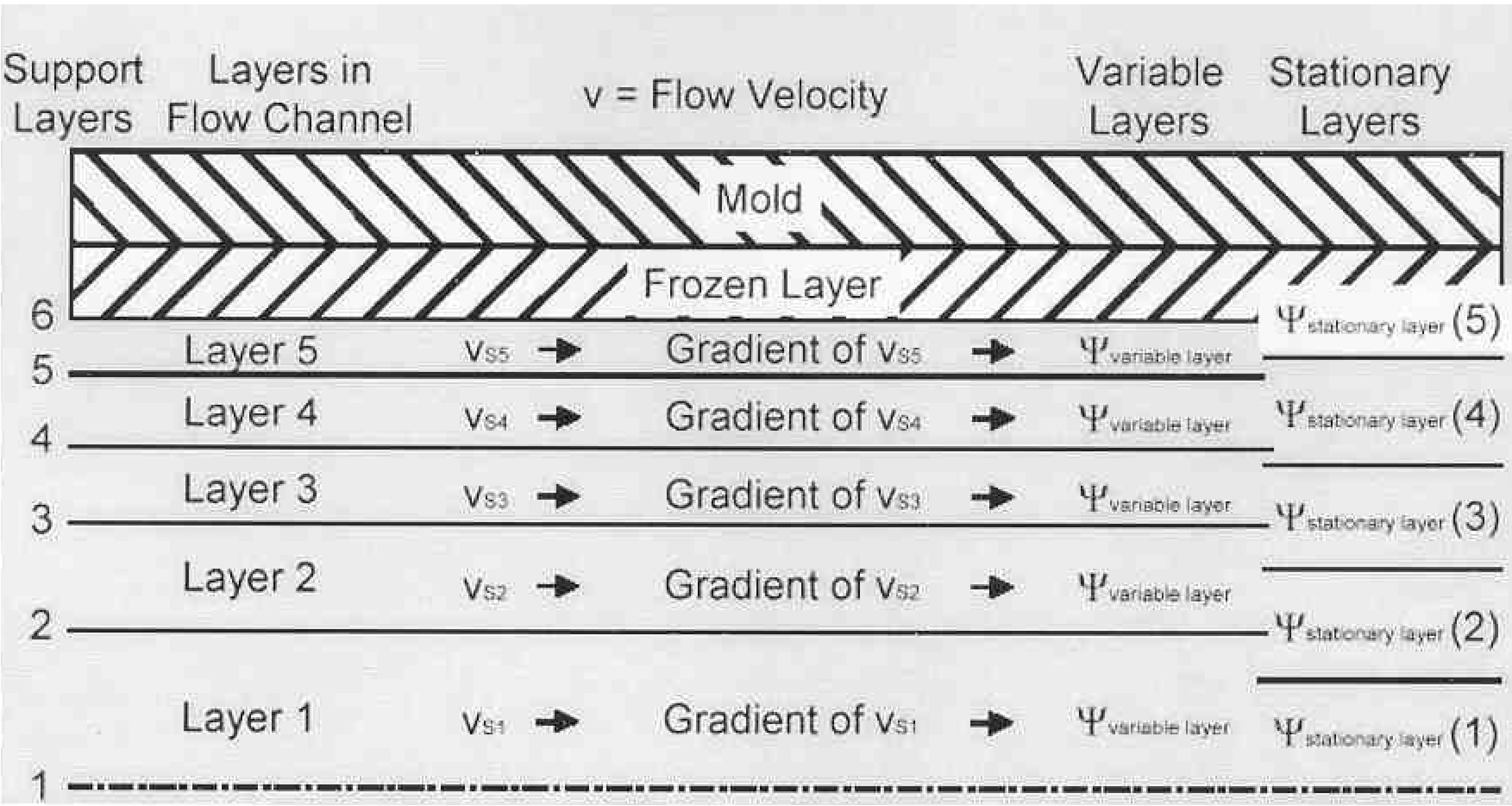
Layer Discrete Fiber Orientation



Fluid velocity of the variable layers $n_m = \dot{g}h_{nS} + n_{m+1}$

Anisotropic Elastic Material Properties

Micromechanics : Halpin-Tsai Equations

$$E_1 = E_M \frac{1 + xk\Phi}{1 - k\Phi}$$

$$x = 2\frac{l_F}{d_F}$$

$$E_2 = E_M \frac{1 + xk\Phi}{1 - k\Phi}$$

$$x = 2$$

$$k = \frac{\frac{E_F}{E_M} - 1}{\frac{E_F}{E_M} + x}$$

$$n_{21} = n_F \Phi + n(1 - \Phi)$$

$$G_{12} = G_M \frac{1 + x\,0.5\Phi}{1 - 0.5\Phi}$$

$$n_{12} = n_{21}\frac{E_2}{E_1}$$

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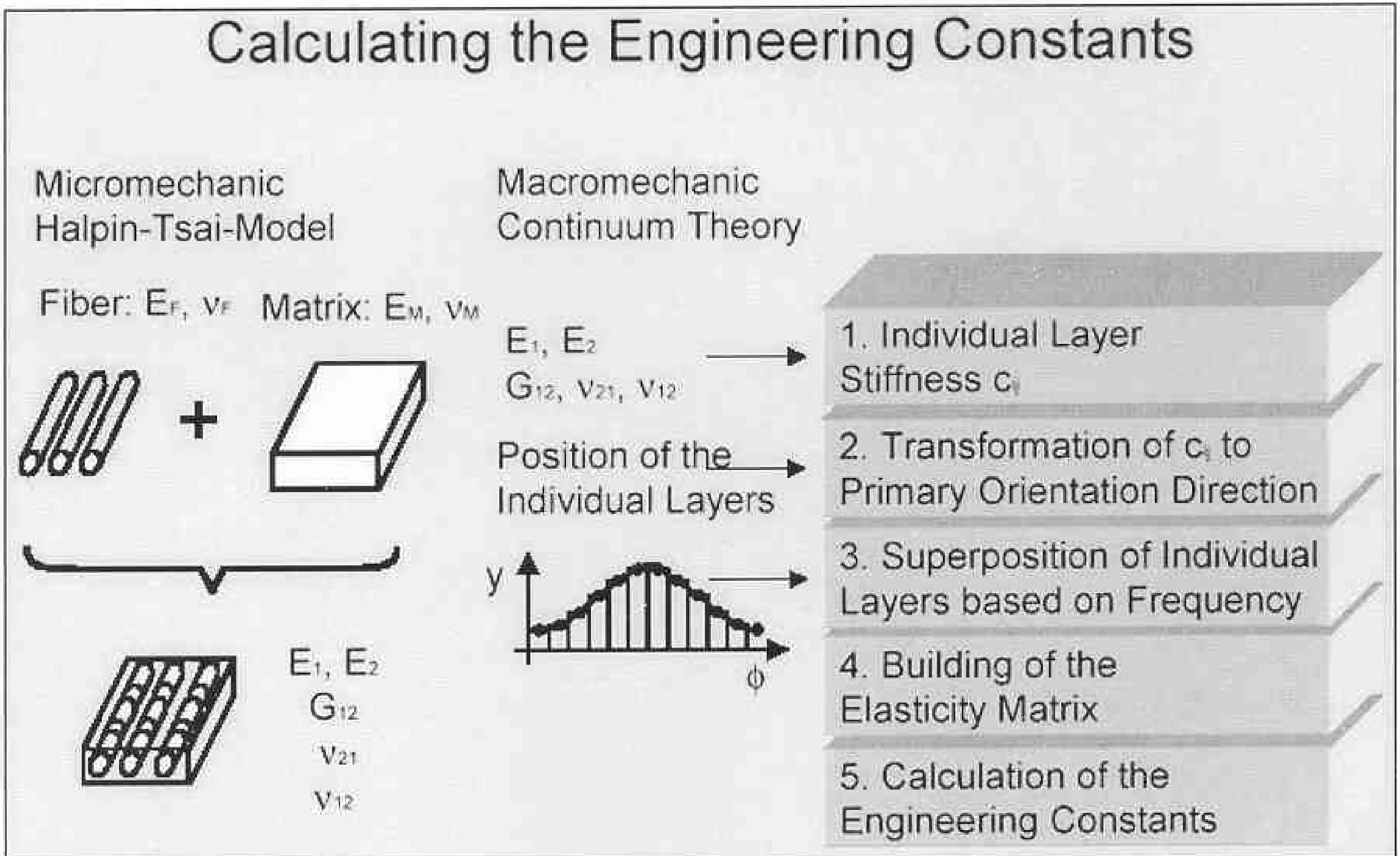
Engineering Constants



Material & Process Data

Coefficient of Thermal Expansion

$$a_M \approx \frac{1}{3} b = \frac{1}{3}\frac{1}{n}\frac{\partial n}{\partial T}$$

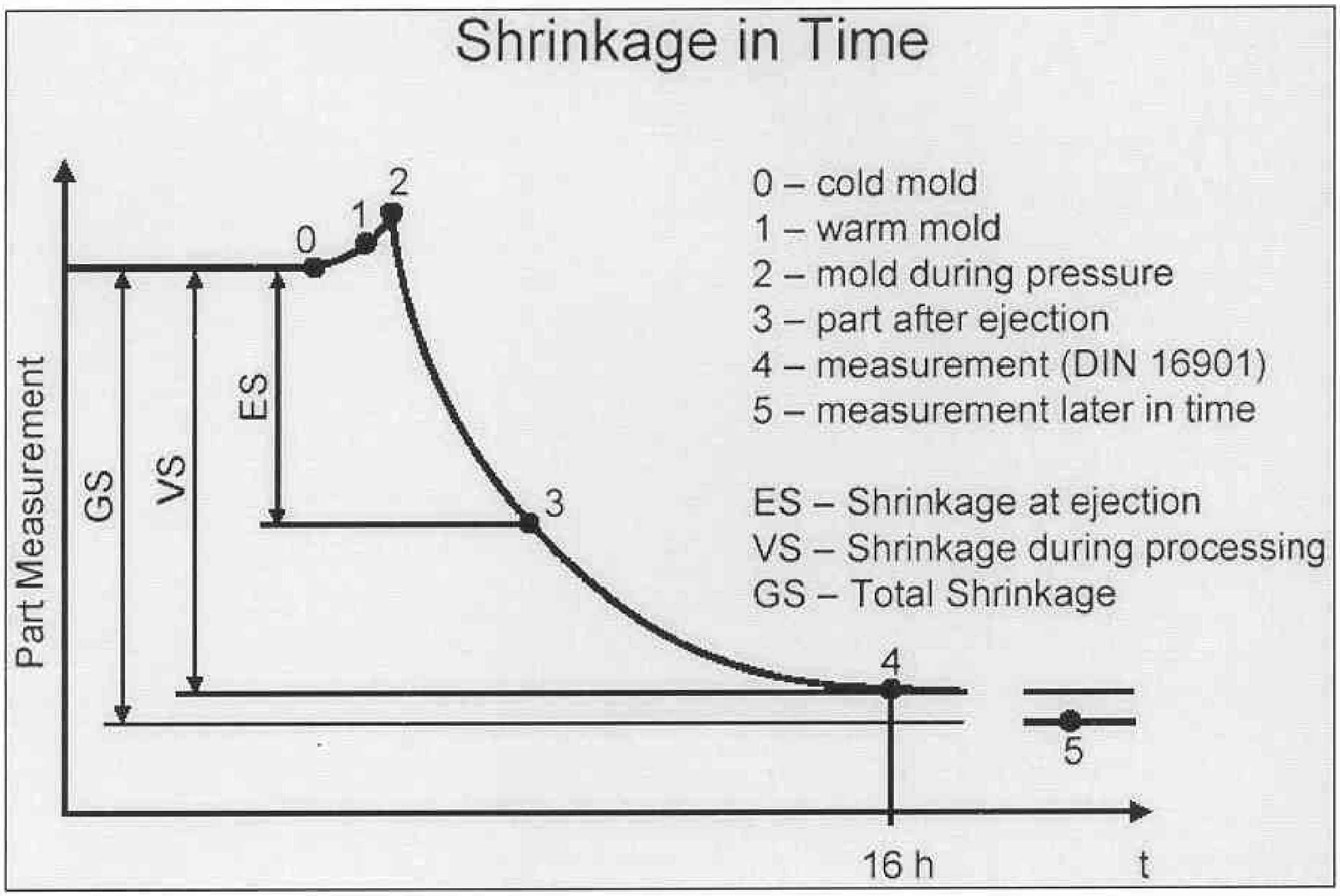
Specific Volume

$$n_M = \frac{K_1}{K_4 + p} + \frac{K_2}{K_3 + p} T + K \ \exp(K_6 T - K_7 p)$$

Coefficient of Thermal Expansion with Temperature & Pressure

$$a_M = \frac{1}{3}\frac{\dfrac{K_{A2}}{p + K_{A3}} + K_{A5} K_{A6} e^{(K_{A6}{}^{T} - K_{A7} p)}}{\dfrac{K_{A1}}{p + K_{A4}} + \dfrac{K_{A2}}{p + K_{A4}} T + K_{A5} K_{A6} e^{(K_{A6} T - K_{A7} p)}}$$

Shrinkage & Warpage



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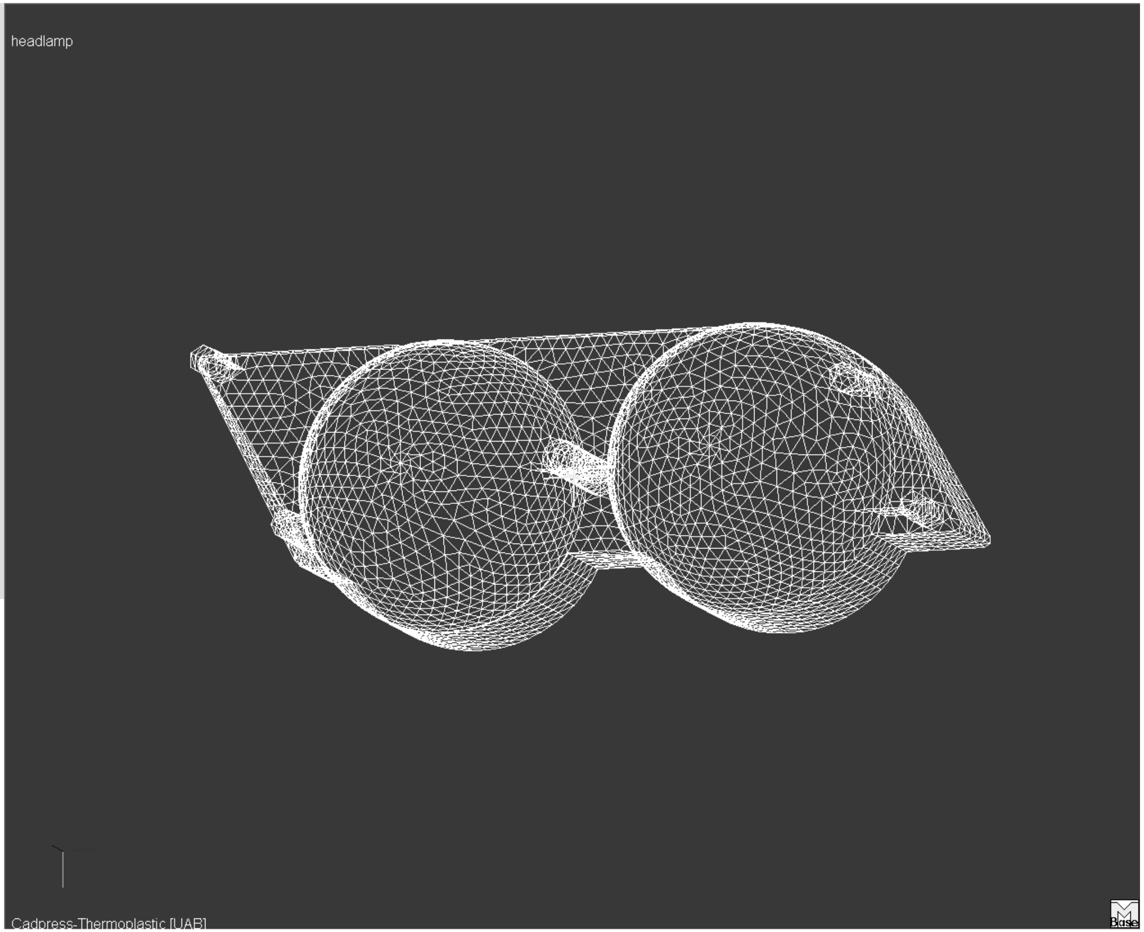
Process Simulation

Mesh Parameters

- Linear Shell elements – 2.5 D
- 3 Noded Tri-Elements
- Mid-plane Model



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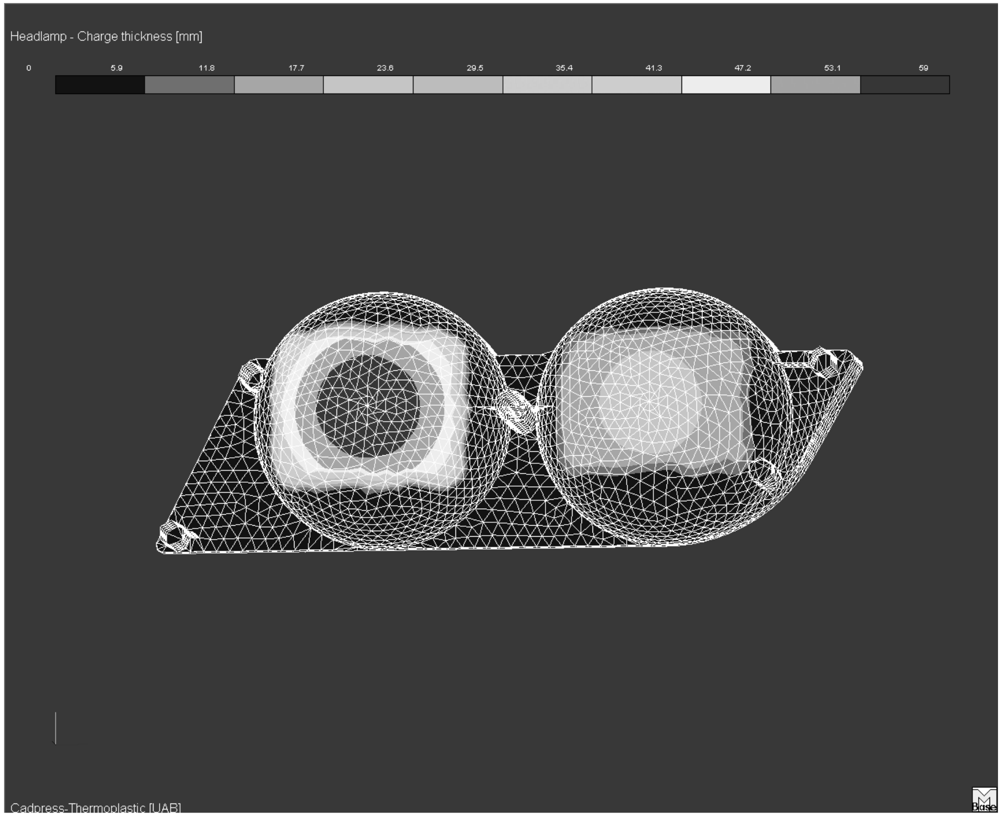
Process Simulation

- ❑ Charge Definition (Group)
- ❑ Closing Vector
- ❑ Closing Rate
- ❑ Molding Compound Temperature
- ❑ Tool Temperature
- ❑ Maximum Pressing Force
- ❑ Pre-orientation of Group



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Process Simulation

Material Data for Flow Simulation

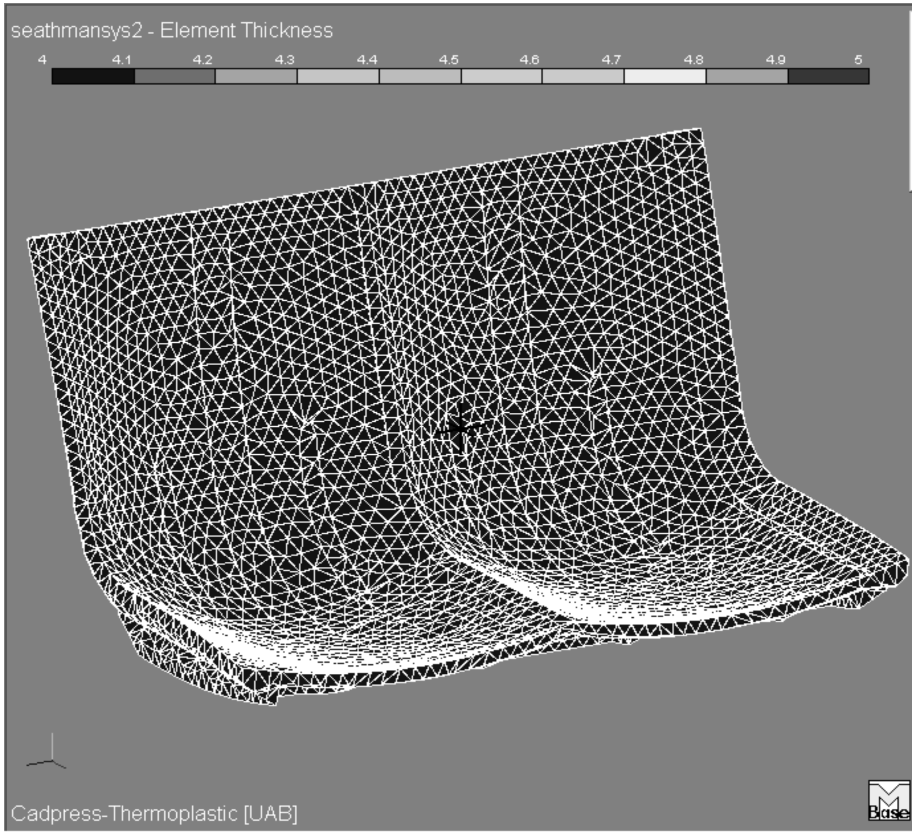
- ❑ Heat Conductivity (W/mK)
- ❑ Thermal Diffusivity (mm^2/s)
- ❑ Heat Transfer Coefficient at Tool (W/mm^2K)
- ❑ Heat Transfer at Air (W/mm^2K)
- ❑ No Flow Temperature (^0C)
- ❑ Fiber Interaction Coefficient
- ❑ Rheometric Parameters

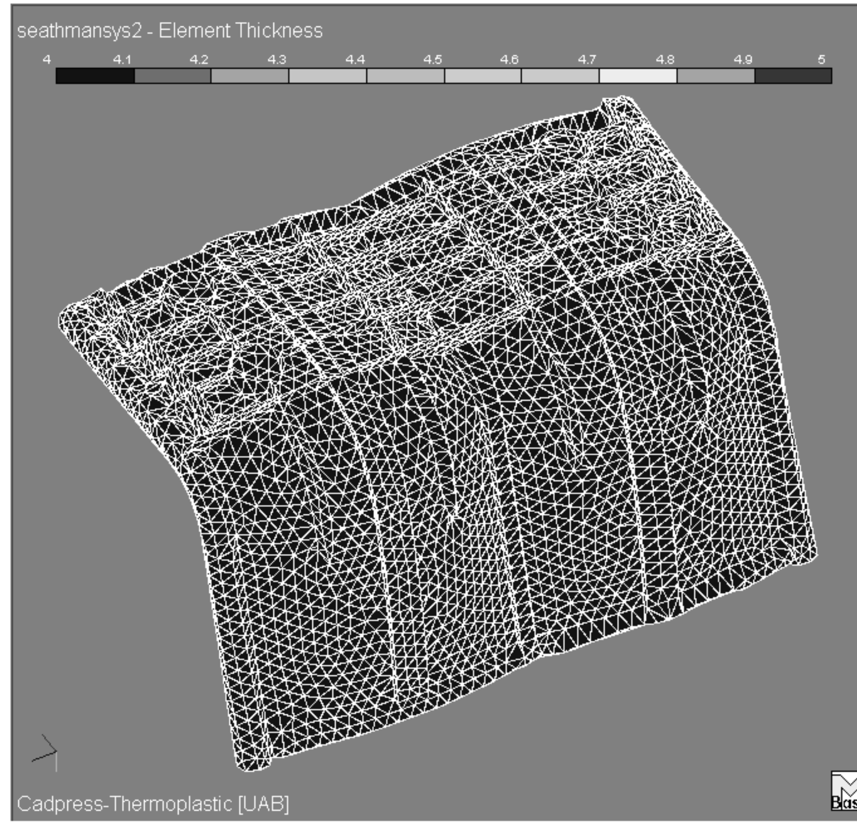
Material Data for Shrinkage & Warpage

❑ Fiber Characteristics

- E-modulus (Pa)
- Poisson's Ratio
- Coefficient of Linear Expansion (1/K)
- Fiber Volume Content
- Length/Diameter of Fiber

Modeling of Bus Seat





Bus seat model was created in Pro/Engineer. Hypermesh was used to mesh the model, and CADpress for Thermoplastics was used for flow simulation

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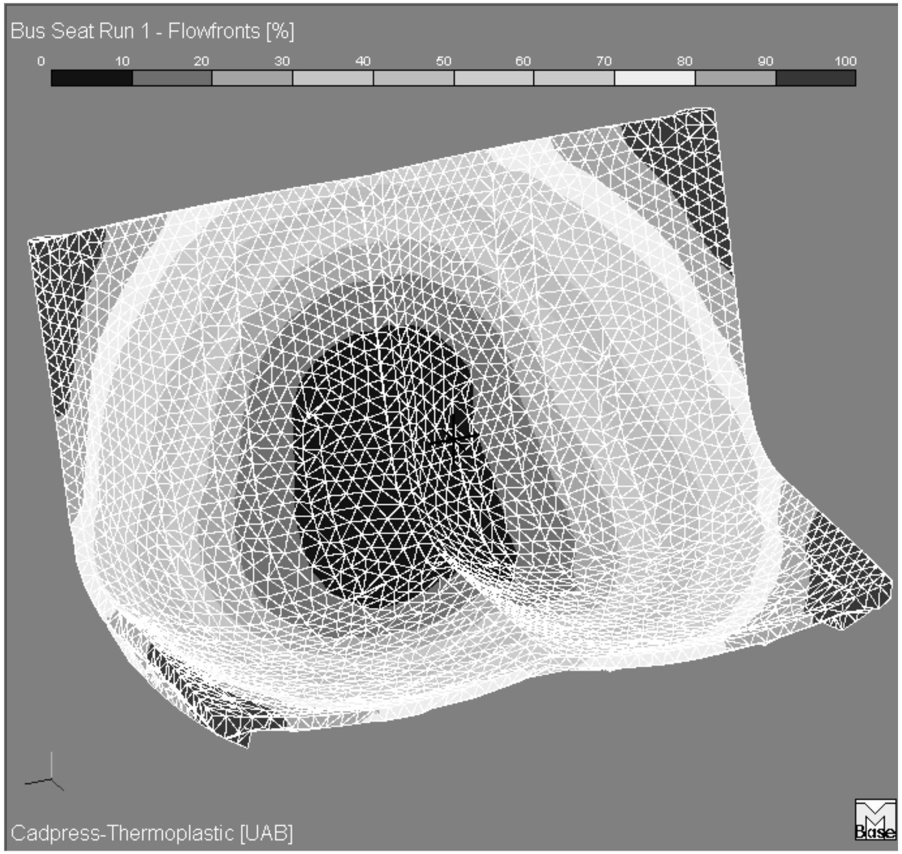
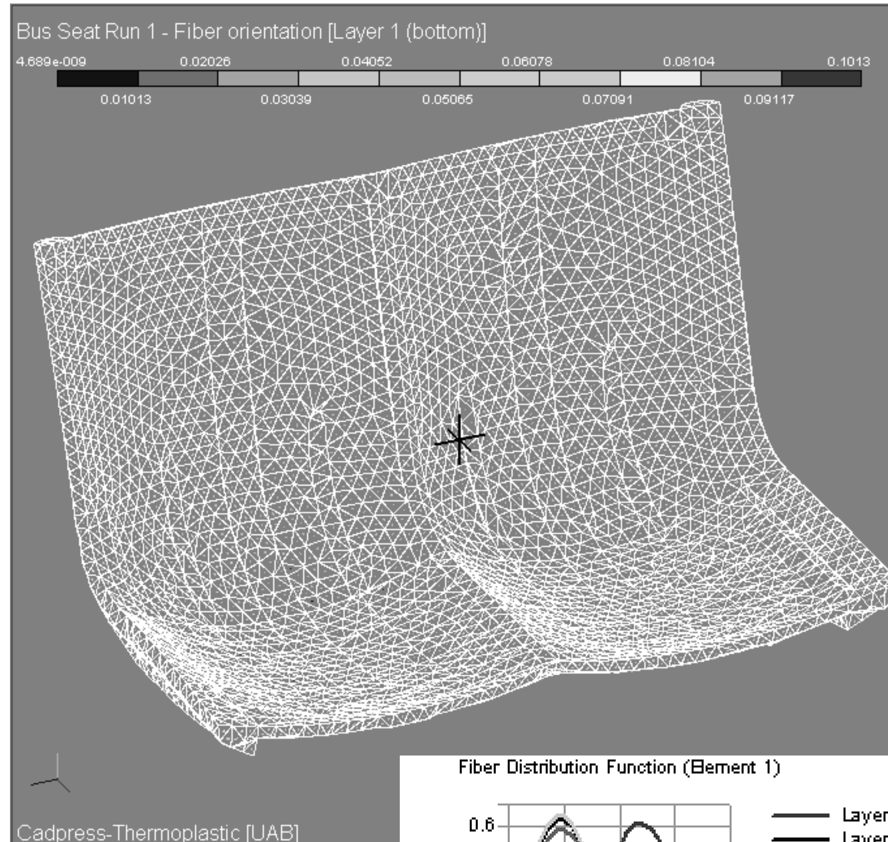
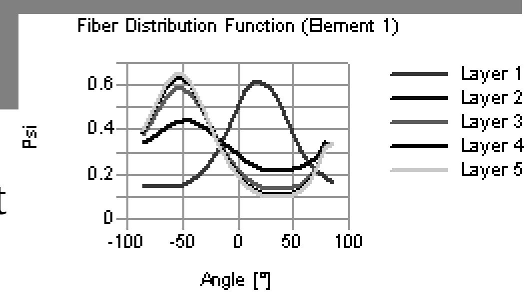
Simulation Extrusion-Compression Molding







Simulation in CADpress for Thermoplastics showing flow front and fiber distribution. The blue region is the charge placement

Actual Part

Short shot
LFT
seat -
to verify
simulation

Summary

Flow simulations conducted for various charge placements using CADpress for Thermoplastics represented closely the physical processing conditions for the bus seat part which was verified through experiments
conducted using short shots

The flow fronts were adequately captured. The predictions of fiber orientation indicated regions of fiber accumulation.

Acknowledgement

Support provided by Federal Transit Administration FTA Project AL-26-7001 is gratefully acknowledged