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Simulation of PTFE Billet Sintering Using COMSOL

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PTFE Advantages

- Exceptional chemical resistance.
- Relatively wide temperature range.
- Thermally stable.
- Low coefficient of friction.

PTFE Billets

- Compression Molding of PTFE resin

  Cylindrical blocks – as large as 15”-20” in diameter
- Sintering- Heating the billet to above the melt temperature of PTFE (650 F)

  Provides Strength & void reduction (suitable for machining), takes time
- Applications

  Thin film skived from cylindrical blocks- Tapes, Sheet

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PTFE Sintering

- Importance of proper sintering:

1)Easily machinable (strength) to make tapes, sheet

2) Under-sintered portion does not have the desired properties

3) Eliminate waste due to rejection of material- PTFE expensive, thereby improve throughput

PTFE Sintering

- To ensure uniform sintering

  a) Center of the billet should get sintered properly

  b)Low thermal conductivity of PTFE → thermal gradient →cracking of the billets

  c) PTFE molecules are less mobile and thus the sintering cycle can be in the order of days

  d) Cooling rate – influences the properties Should not be too fast to avoid large stresses that can fracture the billet.

PTFE Sintering

- Experimental guidelines available

  A typical heating rate is < 50^0C/hr up to 150^0C

  30^0C/hr up to 300^0C and 6 -10^0C/hr at higher temperatures. [Ref:Sina Ebnesajjad]
- Optimum heating rate will depend on –

  the oven conditions (set-point temperature, oven temperature uniformity, load in the oven, airflow rate and air flow configuration) as well as the billet dimensions (diameter and thickness).

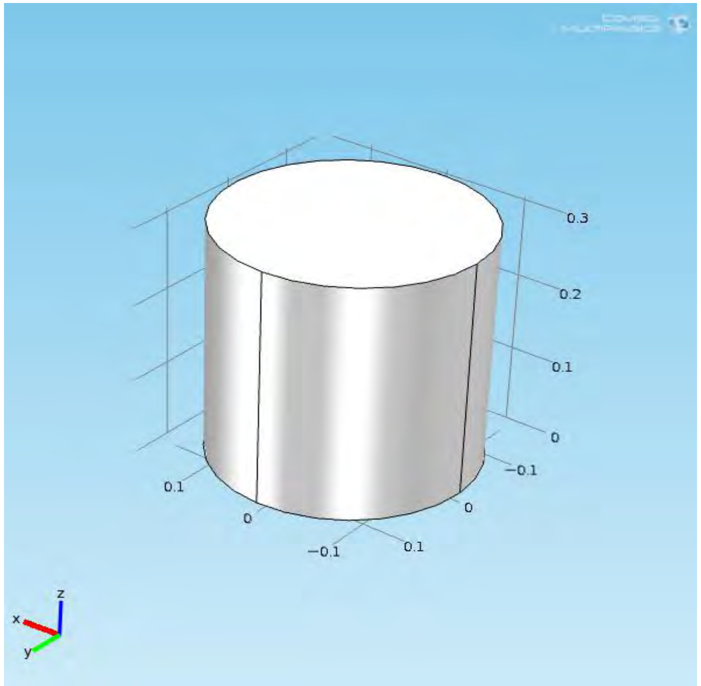
Advantages of modeling

- Quicker results as experimentation takes days. Optimization can be obtained through modeling and confirmed with experimentation
- Non-destructive as thermocouples do not have to be inserted in the material
- Reduces waste during profile optimization
- COMSOL has been found by us to be a very good tool for this modeling application

Present Study- Use of COMSOL

- Optimize the temperature profile (ramps/soaks) in a convection batch oven for given setpoints
- Billet response to temperature studied when the air flow over the billet is both horizontal & vertical
- The results with horizontal air flow obtained when the product is rotated at a constant speed
- Horizontal and vertical air flows have been compared with the case of a constant temperature boundary condition

Temperature Profile optimization



dia-=0.3 m, L=0.3 m

20^0C (T_i) (Initial Cond.)

h= 14 W/m^2K (approx, assumed)

COMSOL Multiphysics Heat Transfer Module has been used

$$\rho C_p \, {}^{\partial T}/_{\partial t} + \nabla.(-k\nabla T) = 0$$ GE

$$-\boldsymbol{n}.(-k\nabla T) = h(T_{ext} - T)$$ BC

(ρ, C_p, k) PTFE resin

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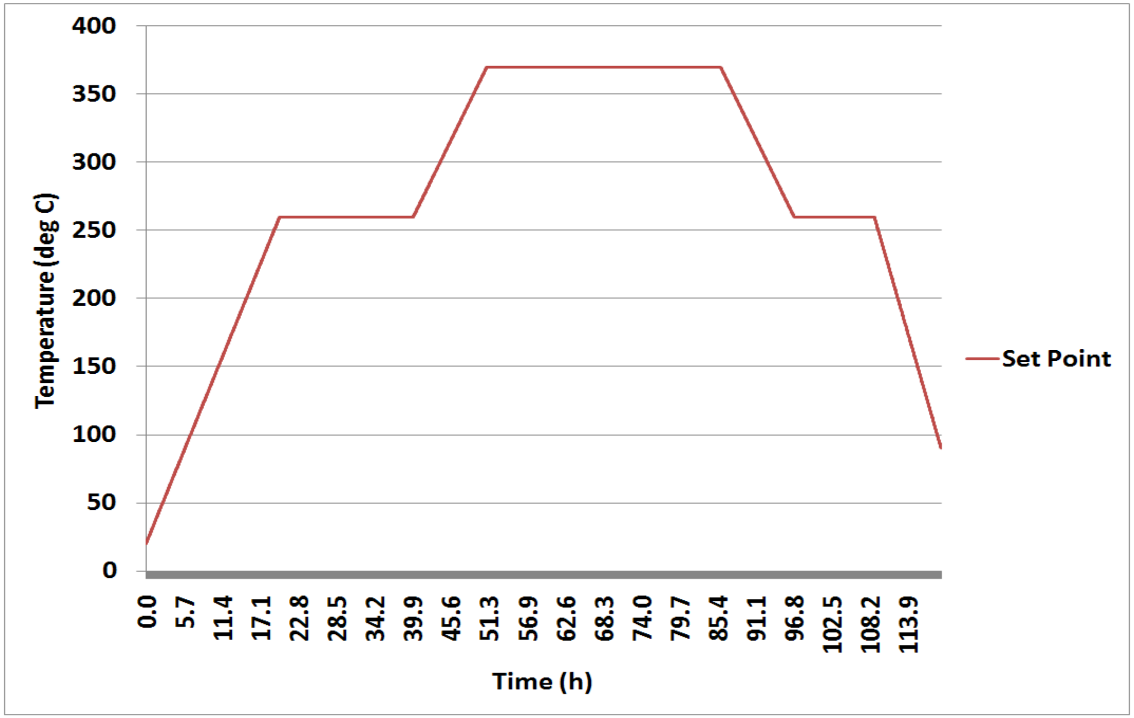
Temperature Profile optimization

Typical Oven set point- Air temperature



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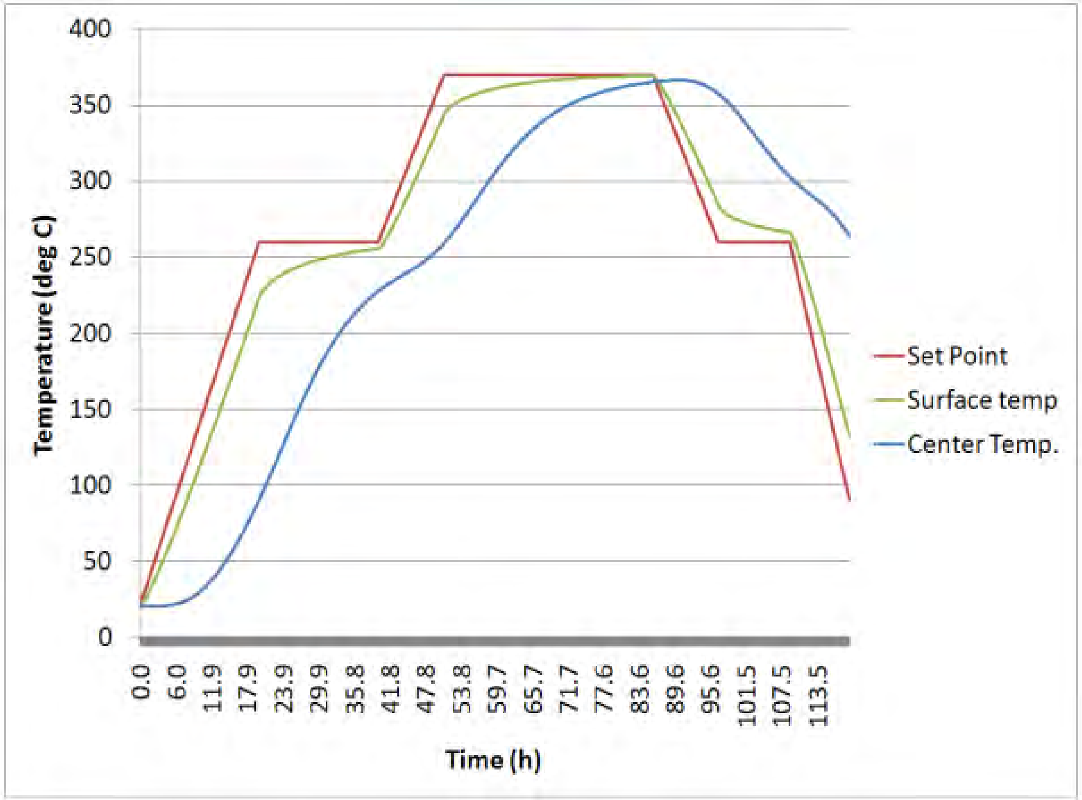
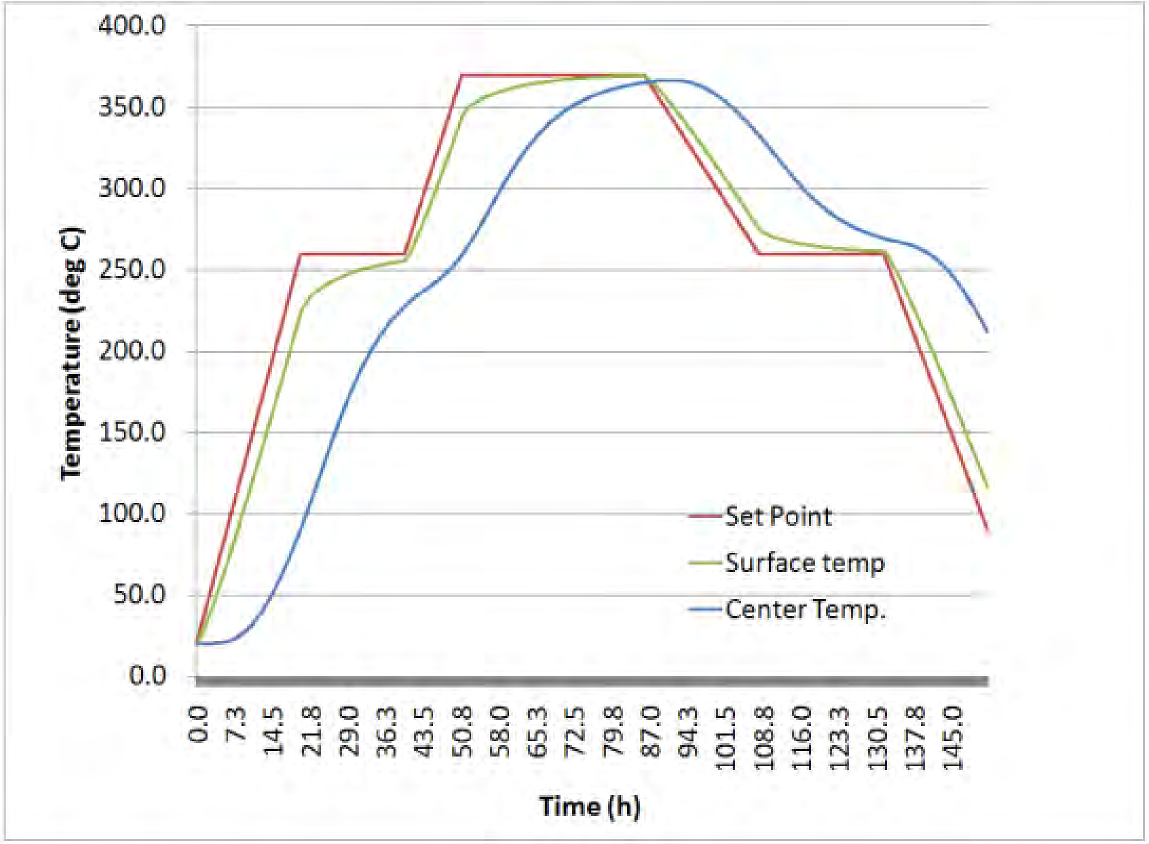
Temperature Profile optimization



Core of the billet lags when compared to the surface temperature due to the low *k values*.

Temperature Profile optimization



- Oven Set Point is modified for the cooling portion
- Decrease in temperature difference between the surface and center during the cooling cycle
- Temp. profile can be still optimized

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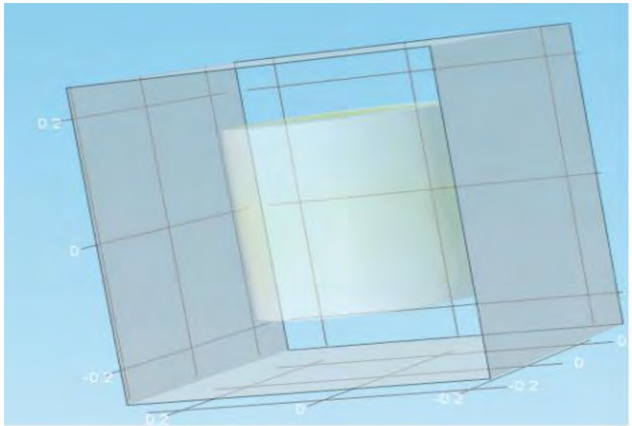
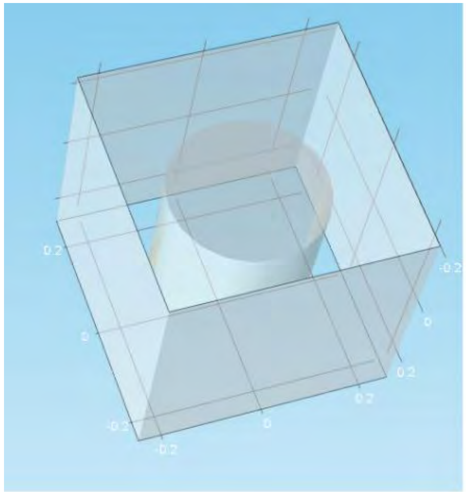
For Horizontal and Vertical Air flow





- The box is a 0.5 m cube
- PTFE billet is initially at 20^0C
- Air flow 4.0 m/s (constant)
- The inlet air temperature is 370^0C

Problems Analyzed

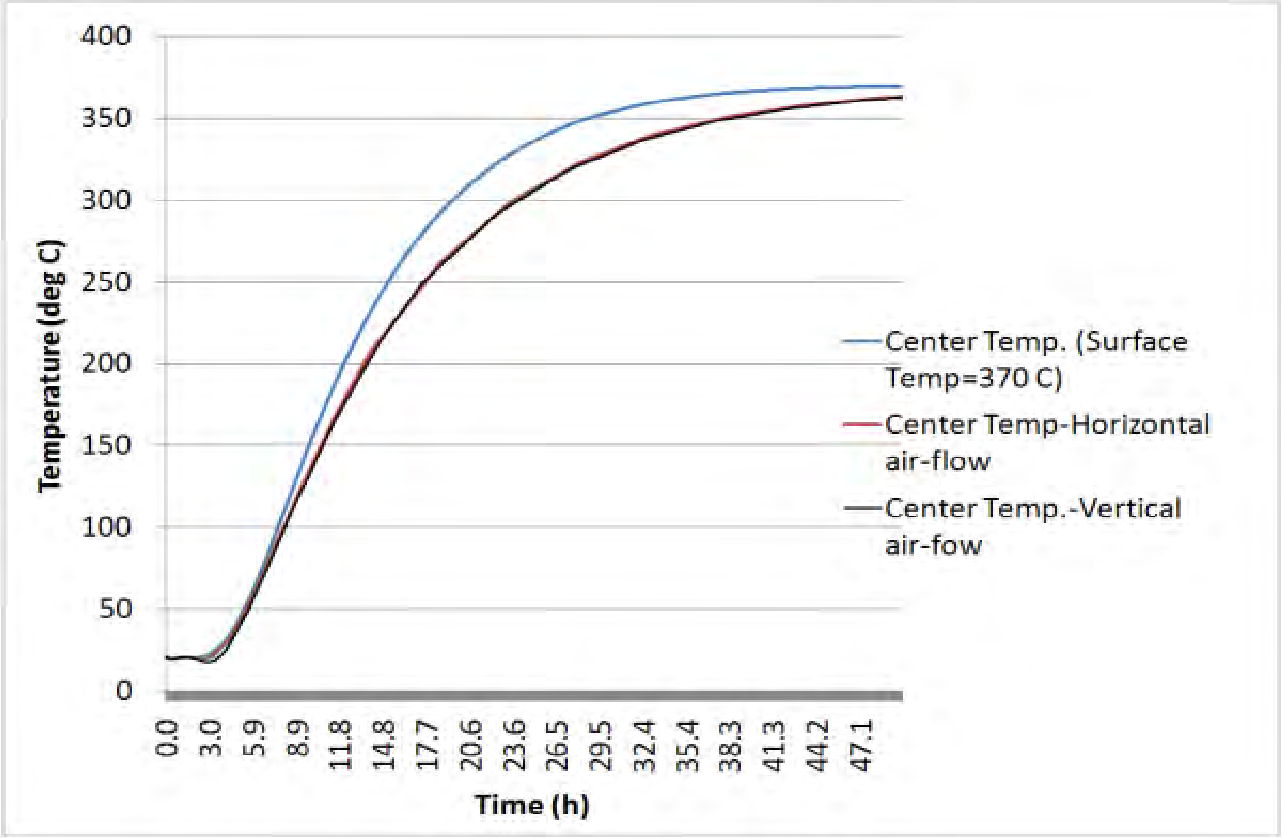
- Surface temperature of the billet instantaneously brought to a temperature of 370^0C from 20^0C

  The convective boundary condition is changed to

$$T_{surface} = T_{ext} = 370°C$$

- For both horizontal and vertical airflow conjugate heat transfer module under COMSOL is used
- No slip boundary condition between the fluid (air) and the billet as well as between the fluid and the inside of the box is considered

Results- Comparison



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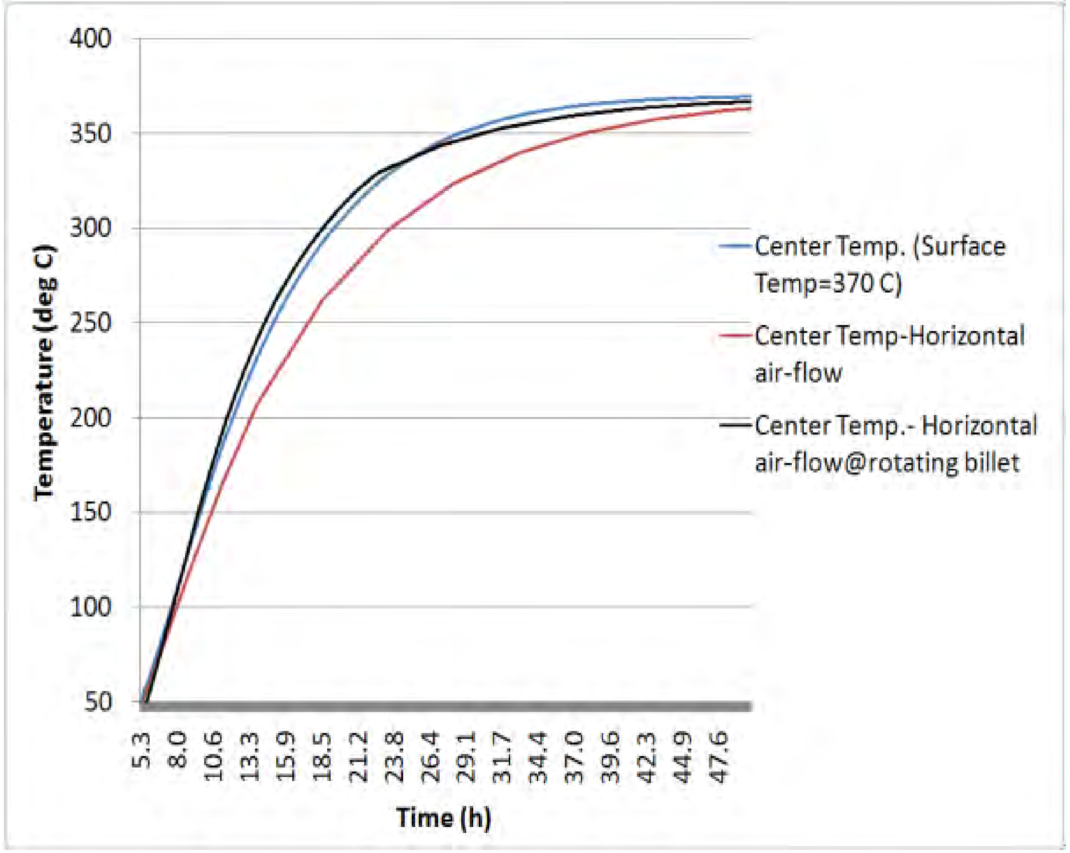
Billet Rotation- Horizontal Flow

- Billet is kept on a turn-table which is rotated at a constant speed (1 rpm) with the air directed at it horizontally.
- The no slip-boundary condition still exists between the air-stream and the inside walls of the rectangular box.
- A sliding wall boundary condition is imposed on the surface of the billet

Billet Rotation- Horizontal Flow



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Conclusions

- The response of the billet to a prescribed oven setpoint was studied for different configurations
- With the use of COMSOL, a better understanding of the temperature profiles is obtained
- Useful information especially for thicker billets that have a tendency to crack during the heating cycle

Conclusions

- In present study-
  1. only one billet was considered being heated
  2. air-temperature perfectly matched the set- points
  3. oven had a perfect temperature uniformity.

- For more realistic oven conditions, COMSOL can aid in improving the efficiencies through optimization of the sintering process.