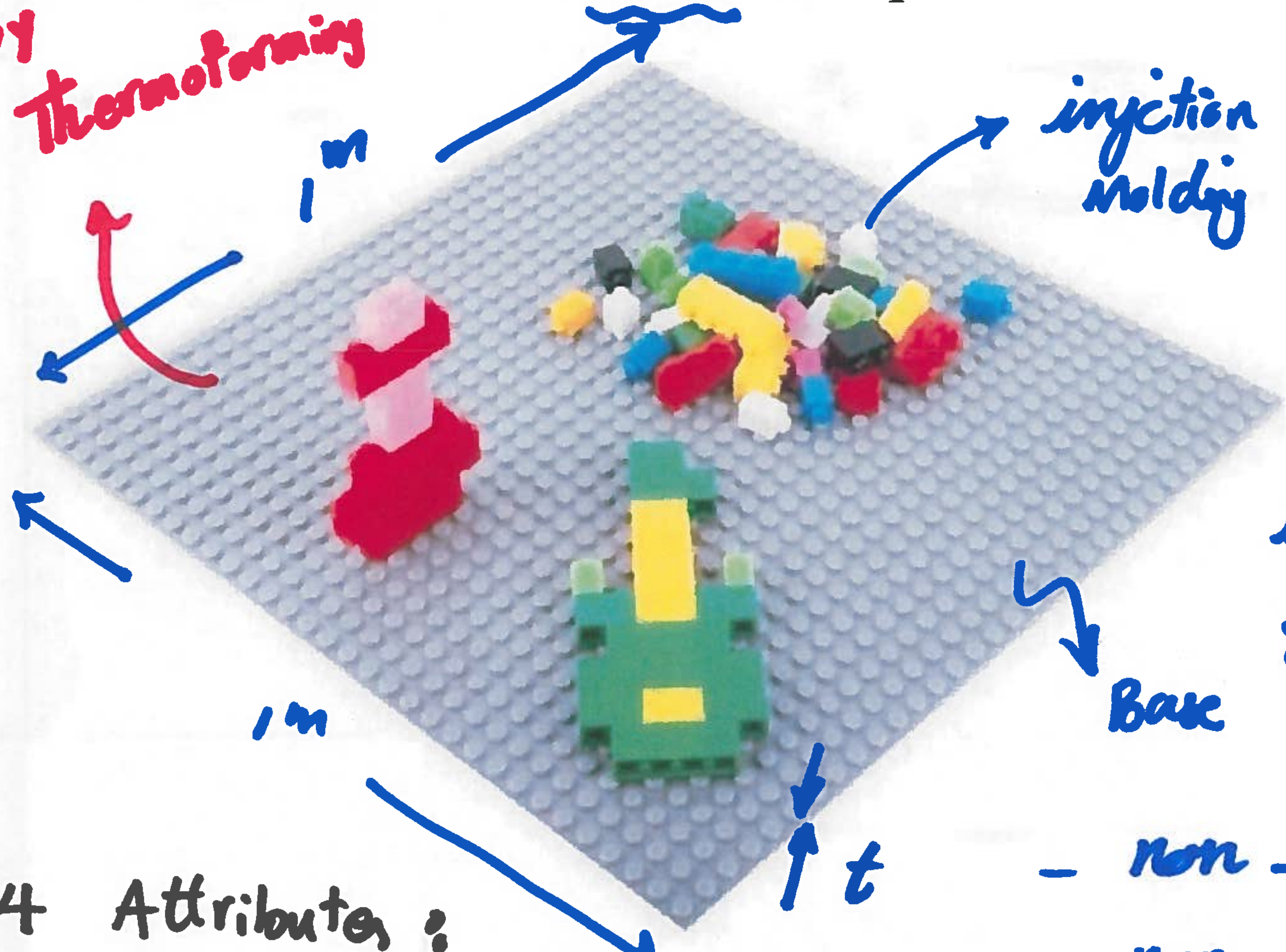
Module 4. Thermoforming

What attributes of the LEGO base plate make it not suitable for injection molding?

by thermoforming



Base

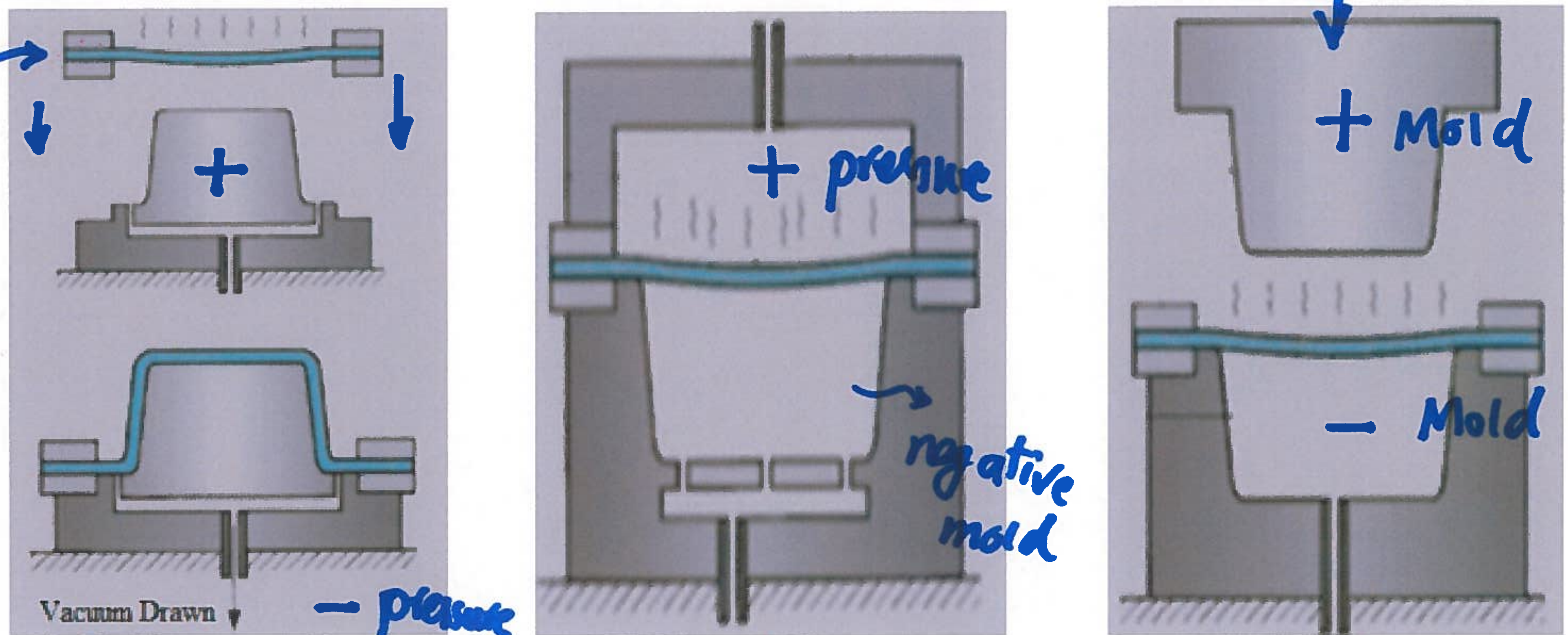
one dimension is significantly smaller than rest $\Longrightarrow$

- non-uniform flow
- non-uniform cooling
- requires extremely large pressure
- " " " clamping force

4 Attributes:

	Cost	Rate	Quality	Flex.
inj.-M (injection Molding)	low	fast	Good	low
thermof.	low	fast	low	low

Thermoforming process: forming a plastic sheet, using heat & pressure.



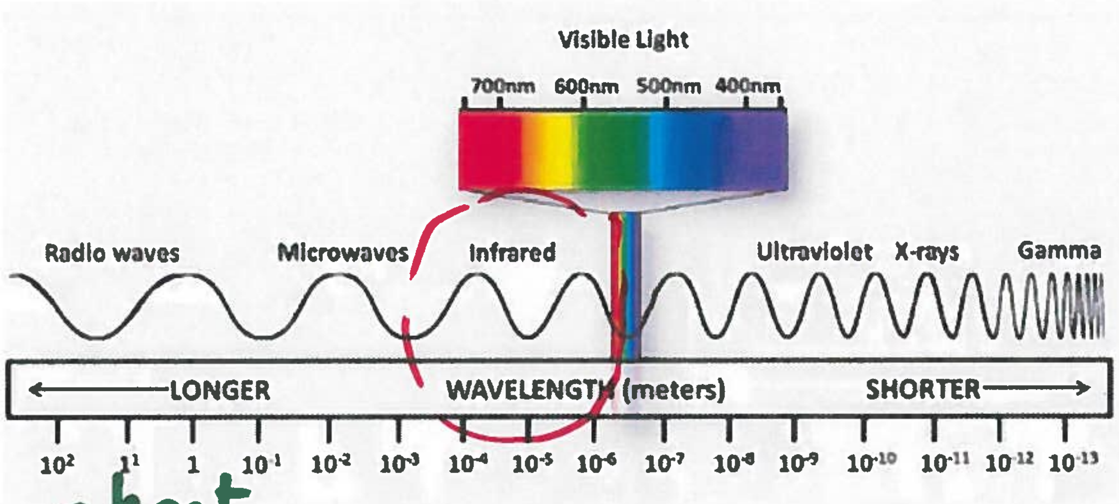
a — Vacuum forming

b — pressure / blow molding

c — * Mechanical thermoforming
→ uniform thickness
→ more expensive

Engineering analysis of thermoforming: $\begin{cases}\text{Heating ?}\\ \text{Stretching ?}\end{cases}$

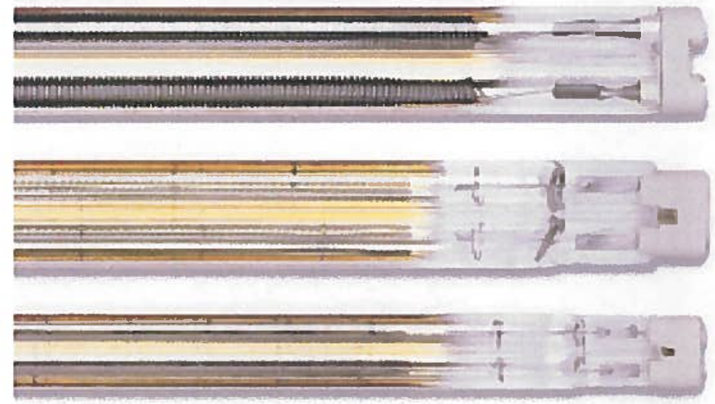
Heating Method: Convective and Radiative heat transfer



IR

How much ?

Heating Lamp Example



Twin-Tube IR Emitter,
Power: 200 Kw/m^2 intensity

https://www.heraeus.com

Heraeus

heat

$$\boxed{q = p \cdot a}$$

lamp (Power intensity p)

plastic $0.6 < a < 0.9$

ABS , $a = 0.8$

$q = 200000 \times 0.8$ w

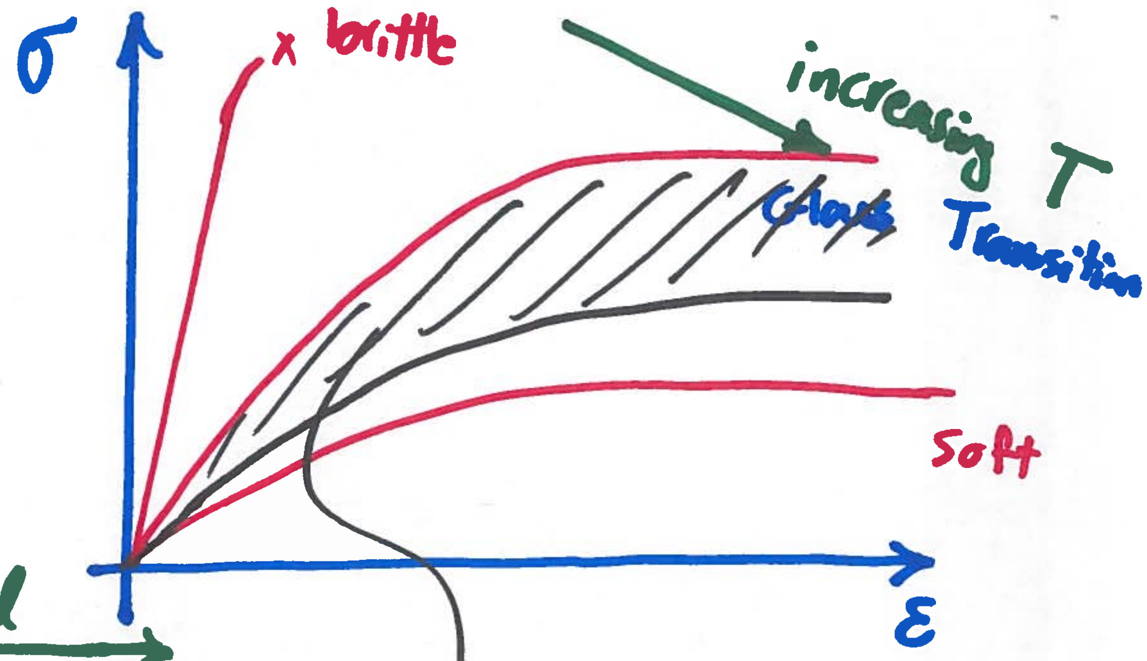
plastic sheet (heat absorption coefficient of a)

depends on (..., c_p , density , color , material property)

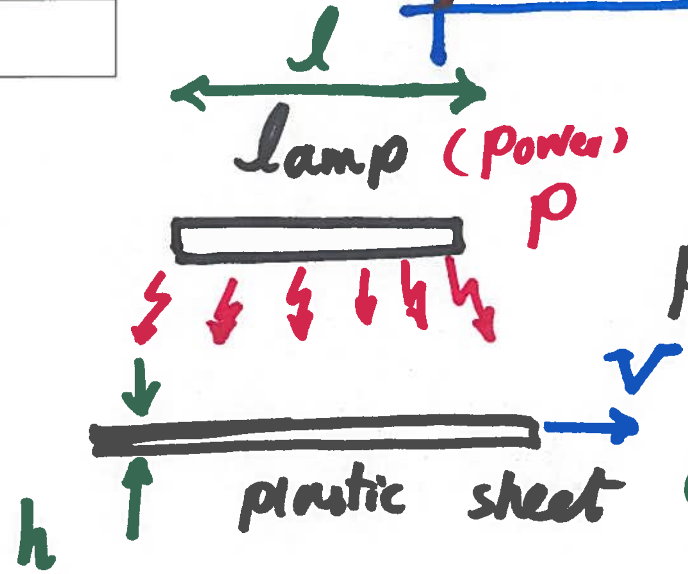
Exposure Time for Heating:

Temperature Range:

Polymer	**Suggested Temperature (°C)**
PS (PolyStyrene)	135 -150
ABS (Acrylonitrile Butadiene Styrene)	140-150 145
PVC (Poly Vinyl Chloride)	110-140
PP (Poly Pro Pylene)	150-175



How long a plastic sheet must be exposed to the heat source?



(a) T_{form} → we decide t_{heat}

$q = P \cdot a$

$$\frac{dT}{dt} = \frac{q \cdot A}{mC_p} = \frac{q \cdot A}{A\rho h c_p} = \frac{q}{\rho h c_p} = \frac{P \cdot a}{\rho h c_p} \Rightarrow \int_{T_{room}}^{T_{form}} dT = \int_0^{t_{heat}} \left(\frac{Pa}{\rho h c_p}\right) dt$$

$$\boxed{t_{heat} = \frac{\rho h c_p}{Pa}(T_f - T_r)}$$

in continuous forming: $v_{feed} = \frac{l}{t_{heat}}$

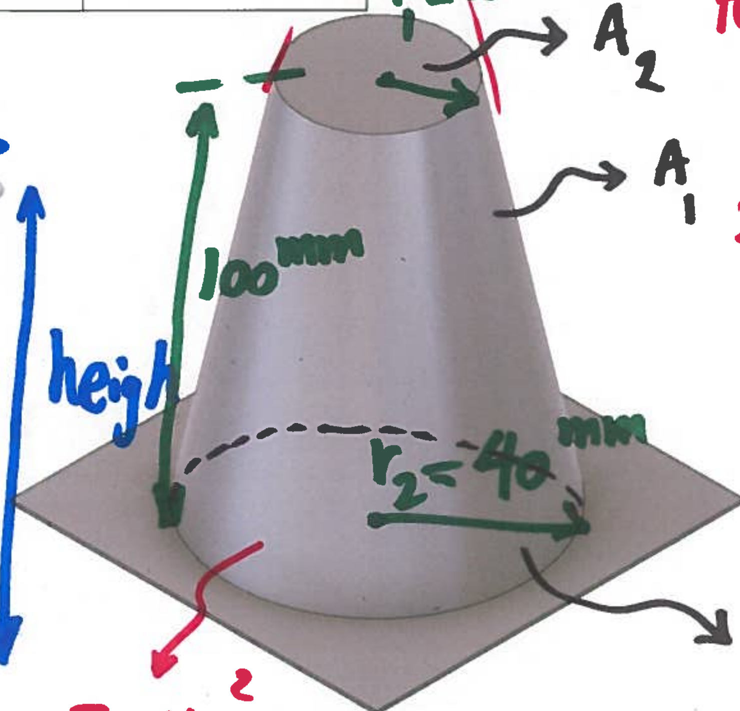
How much a plastic can be stretched?

$$R_A = \frac{\textit{Surface area of formed part}}{\textit{Surface area of foot print}}$$ (Areal draw Ratio)

projected are / Area of plastic used to form the part

Polymer	Max R_A
PS (PolyStyrene)	2.5
ABS (Acrylonitrile Butadiene Styrene)	5.5
PVC (Poly Vinyl Chloride)	4.2
PP (Poly Pro Pylene)	7.5

* rule of thumb: the ratio of $\frac{\text{width}}{\text{heigh}} > \frac{1}{3}$



A_2 $\pi \times 20^2 = 1200\ mm^2$

A_1 $22000\ mm^2$

$(A_1 + A_2)$

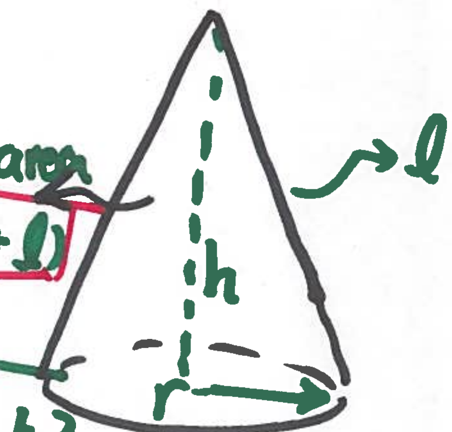
$\pi \times 40^2 \simeq 5000$

projected area A_3

$$R_A = \frac{A_1 + A_2}{A_3}$$

$$R_A = \frac{23000}{5000} = 4.6$$

Cone area $\boxed{\pi r(r+l)}$



$l = \sqrt{r^2 + h^2}$

Summary:

Required time to heat plastic to get to T_{form}

$$t_{heat} = \frac{\rho h c_p}{P a}(T_{form} - T_{room})$$

lamp property

absorption coef.

we decide, based on the material & the processing window

ex.

ABS 145C

PVC 120C

Continious forming: $V_{feed} = \frac{l}{t_{heat}}$

length of lamp

$$R_A = \frac{\text{Surface area of formed part}}{\text{Projected area}}$$

max limit for R_A:

ABS	5.5
PVC	4.2