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MUSP

Macchine Utensili e Sistemi di Produzione

A Model of Gas Bubble Growth by Comsol Multiphysics

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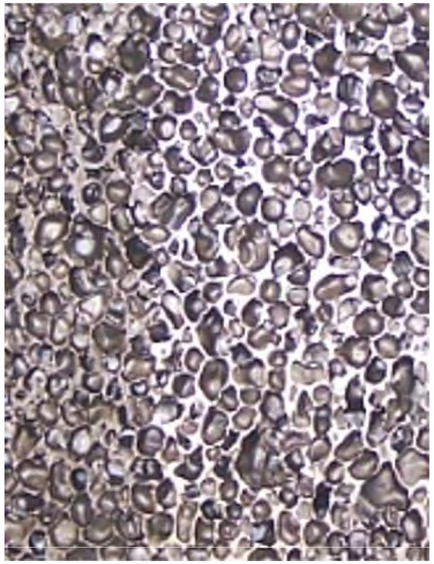
Outline of the presentation



- Introduction
- Metal foams and bubbles growth
- Bubble growth model
- Simulations by Comsol Multiphysics
- Results
- Conclusions

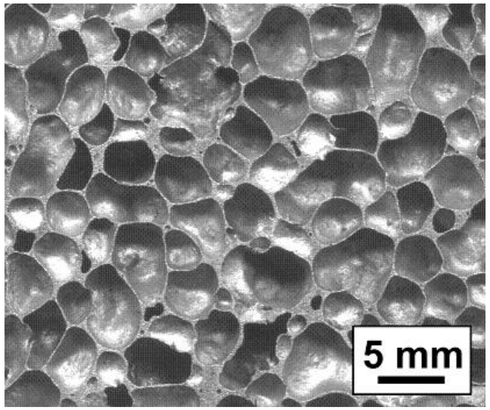
Metal foams

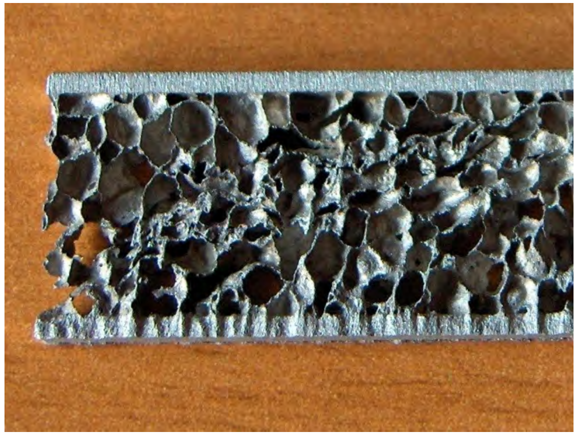
Uniform gas-liquid mixture (gas-metal or gas-alloy) in which the volume fraction of the liquid phase is small (10-20%: wet foam, <10% dry foam)

D.J. Durian (UCLA): ...*a random packing of bubbles*...

or ...*a most unusual form of condensed matter*...

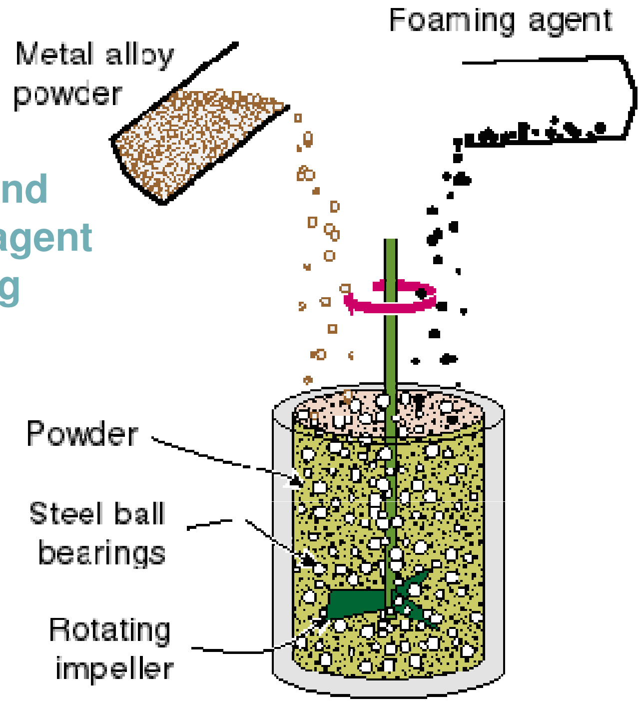
solidification → solidified metal foam



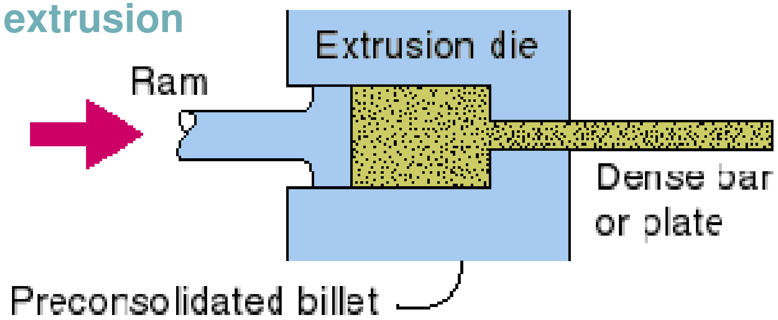


Process and bubble growth

Metal and foaming agent mixing



Consolidation and extrusion



- mixing of the foaming agent powder to obtain a uniform distribution in the base metal powder
- powder cold compaction in order to break the oxide layer covering the aluminium particle
- extrusion of the pre-compacted billet in order to obtain a precursor material whose density is close to that of the base metal

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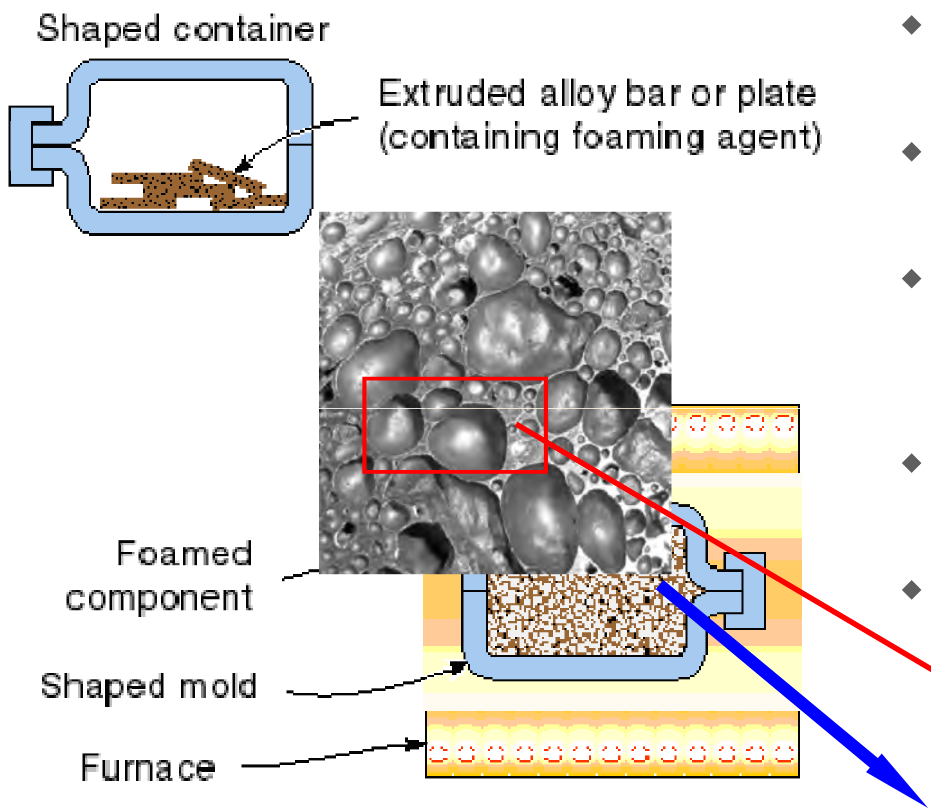
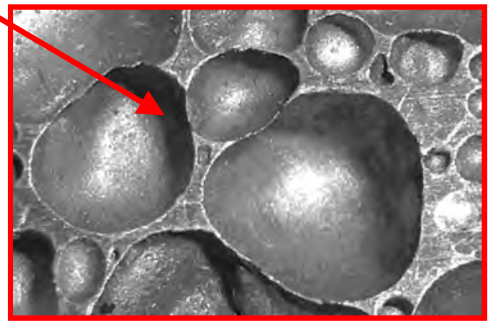
Process and bubble growth

Shaped mould



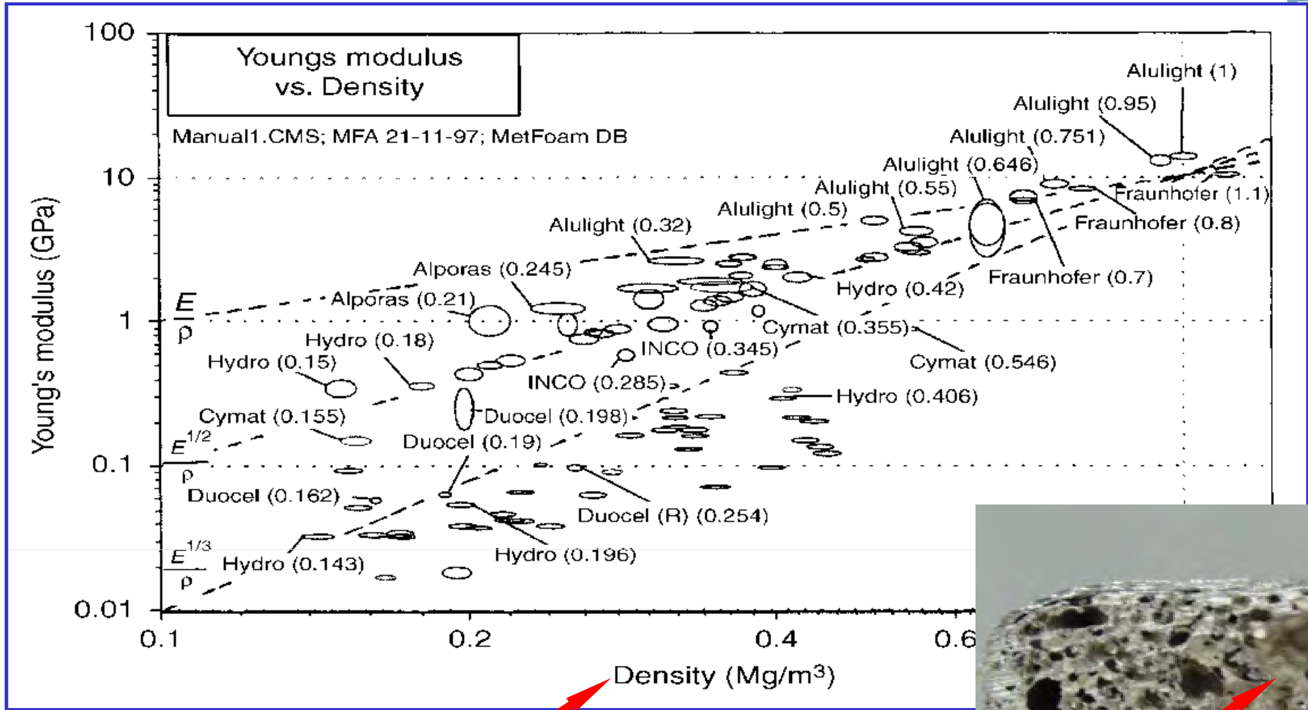
- chopping of the precursor material in small pieces
- placing inside a sealed split mould
- heating to a temperature a little above the solidus temperature of the alloy
- foaming agent decomposition and foam formation
- cooling and extraction



Foaming process

echanisms

notion

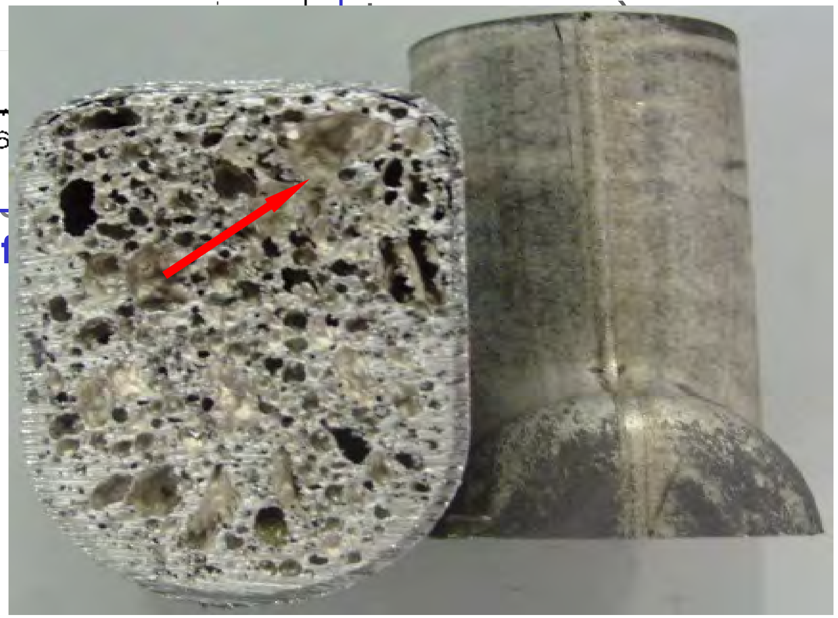


mechanical properties of solids ...

ρ/ρ_s , ρ = foam density, ρ_s = density of

- to reduce ***defects of pieces*** is need

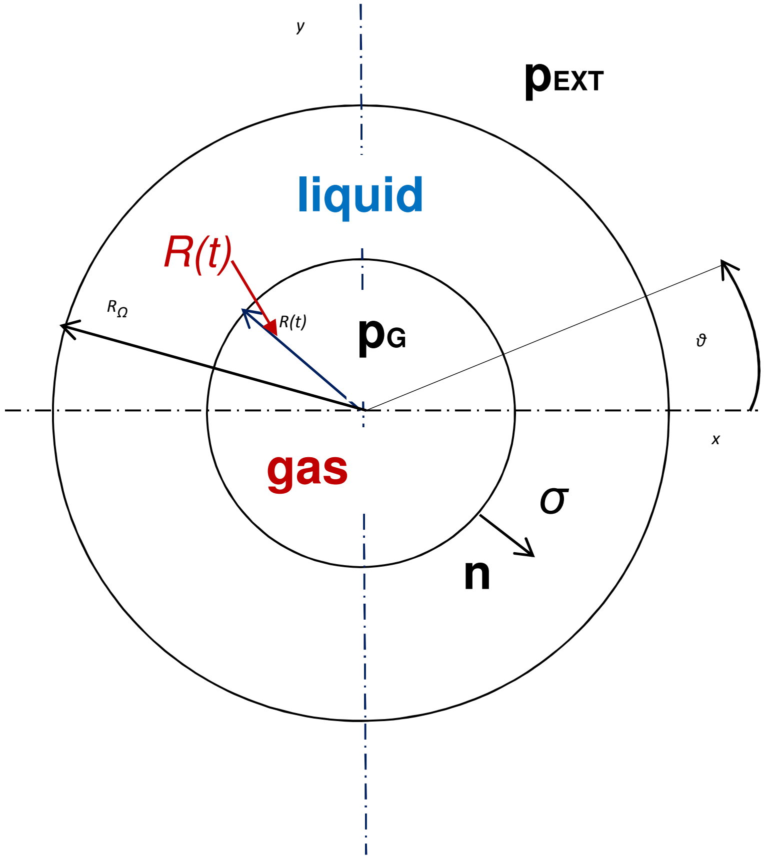
filling process



A bubble growth model

At the beginning, simplified models may be used to study metal foaming processes.

- transient bubble growth in a 2D region, circular symmetry
- isothermal, no mass diffusion: growth is only driven by a pressure difference, surface tension σ effects are considered
- gas follows the ideal gas law $pV = n\Re T$, liquid is incompressible
- gas and liquid are immiscible

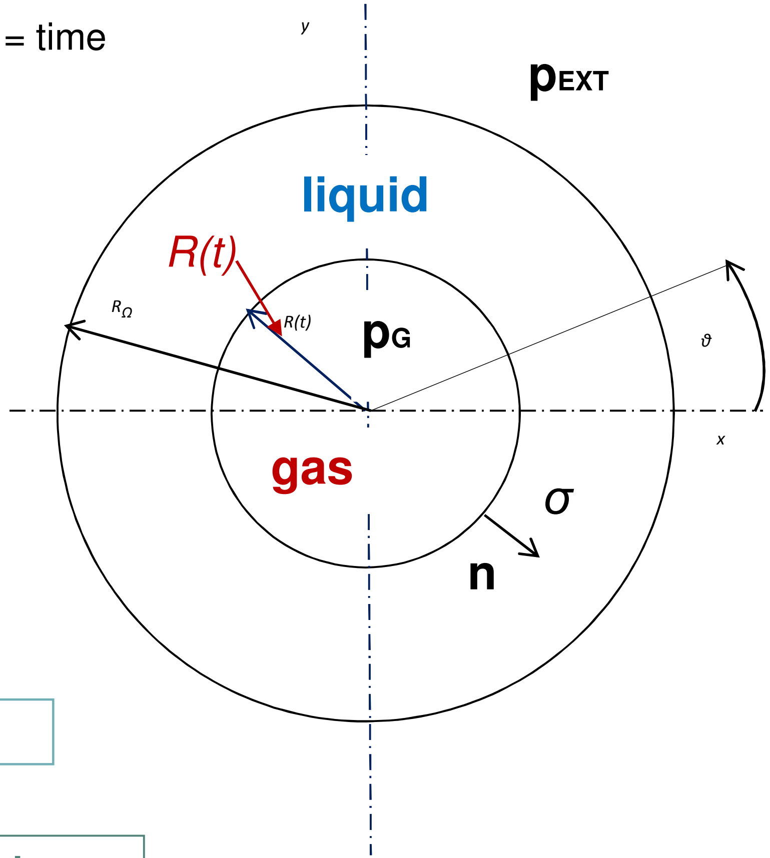


A bubble growth model

$$R_0 = \frac{\sigma}{p_{G,0} - p_{EXT,0}}$$ t = 0, equilibrium

$$R_{eq} = \frac{\sigma}{p_G - p_{EXT}}$$ t = t fin, equilibrium

t = time



Comsol Multiphysics:

Two Phase Flow, Level Set Application Mode
Weakly-Compressible

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \mathbf{u}) = 0$$ continuity

$$\rho \frac{\partial \mathbf{u}}{\partial t} + \rho (\mathbf{u} \cdot \nabla)\mathbf{u} = \nabla \cdot [-p\mathbf{I} + \eta(\nabla \mathbf{u} + (\nabla \mathbf{u})^T)$$
$$-(\frac{2\eta}{3} - \kappa_{DV})(\nabla \cdot \mathbf{u})\mathbf{I}] + \mathbf{F} + \rho \mathbf{g} + \mathbf{F}_{ST}$$ momentum

$$\frac{\partial \phi}{\partial t} + \mathbf{u} \cdot \nabla \phi = \gamma \nabla \cdot [\varepsilon \nabla \phi - \phi(1-\phi)\frac{\nabla \phi}{|\nabla \phi|}]$$ level set

A bubble growth model

equations for gas density

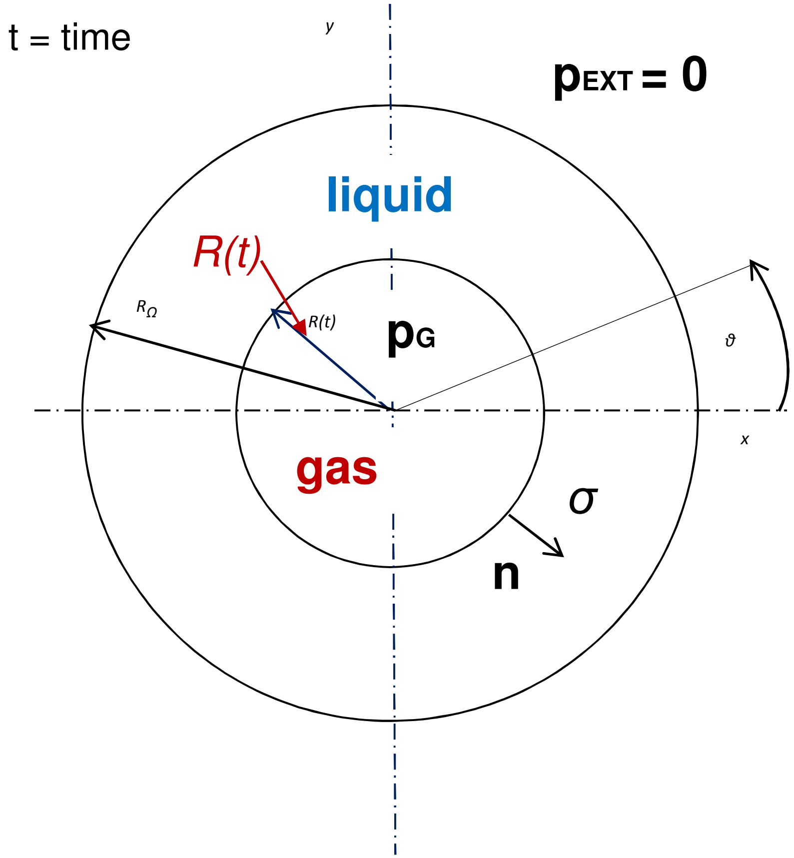
- if $\sigma = 0$:

$$\rho_G(t) = \frac{\rho_{G,0}}{(1 + \frac{p_{G,0}\, t}{\eta_L})}$$

- if $\sigma \neq 0$:

$$[C - AR(t)]^C \exp^{AR(t)} = [C - AR_0]^C \exp^{A(R_0 - At)}$$

$$C = \frac{p_{G,0} R_0^{\ 2}}{2\eta_L}, \qquad A = \frac{\sigma}{2\eta_L} \Rightarrow \rho_G(t)$$



Simulations: properties and parameters

Magnitude	Symbol	Value
Universal gas constant		8.314 J/(mol·K)
Gas molar mass	M	2 g/mol
Gas density	ρ_G	ideal gas law
Liquid density	ρ_L	10 kg/m^3
Gas viscosity	η_G	10^{-3} Pa·s
Liquid viscosity	η_L	10^{-1} Pa·s
Gas bulk viscosity	κ_{DV}	0 Pa·s
Surface tension coefficient	σ	0 N/m
		10^{-2} N/m
Initial bubble radius	R_0	10^{-2} m
Initial bubble pressure	$p_{G,0}$	0.2 Pa
		1.2 Pa; 2.2 Pa
Ambient pressure	p_{EXT}	0 Pa
Constant temperature	T	933 K

$$\frac{\rho_L}{\rho_{G,0}} \cong 4x10^2$$

$$\frac{\eta_L}{\eta_G} \cong 10^2$$

Magnitude	Symbol	Value
Max element size of the mesh	-	10^{-4} m
Time stepping	-	set by the solver
Relative tolerance	-	10^{-3} s
Absolute tolerance	-	10^{-4} s
Interface thickness	ε	10^{-4} m
Reinitialization	γ	0.01 - 0.02 m/s

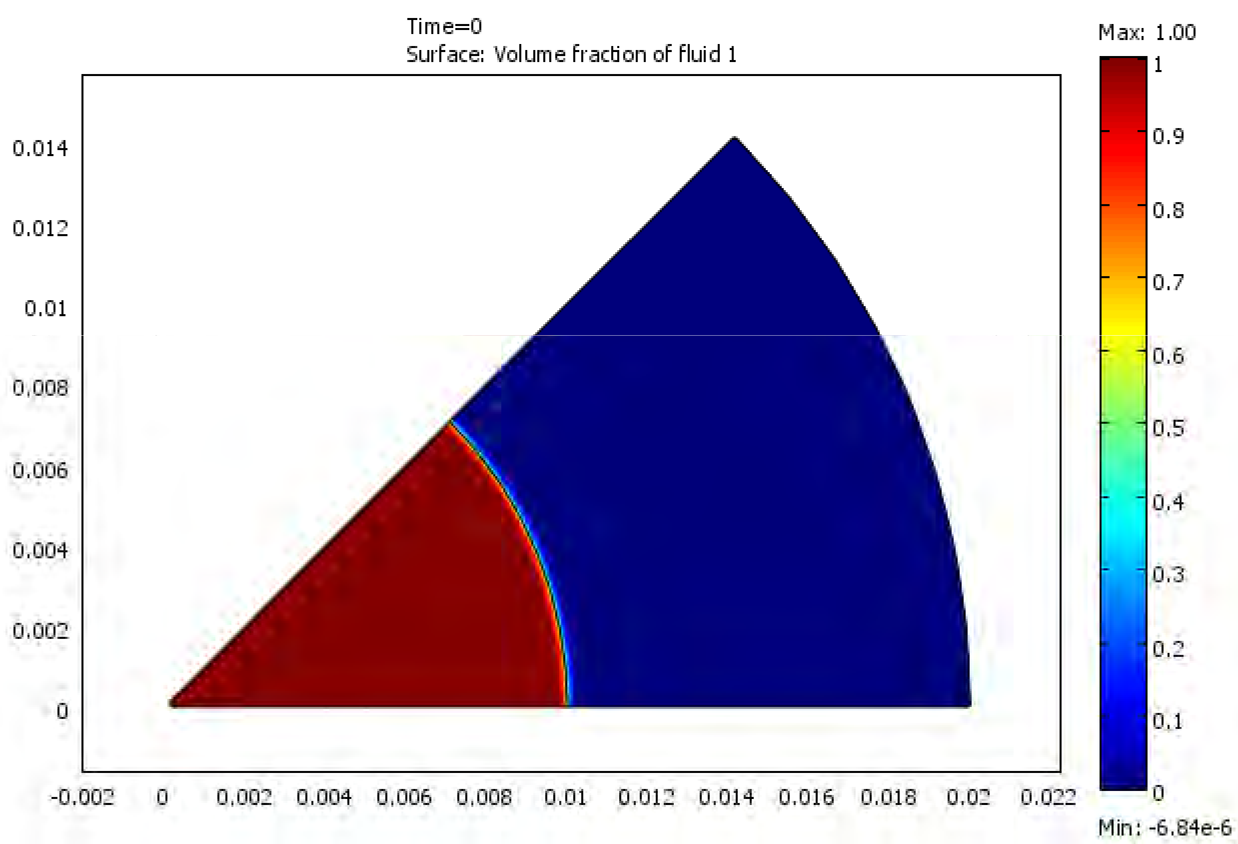
mesh : 10^4 triangle elements

$8x10^4$ DOF

Direct solver PARDISO (*Comsol Multiphysics* 3.5*a*)

step size $\cong 10^{-3} s$, solution time $\cong 10^2$ min $(f(t_{fin}))$

Results

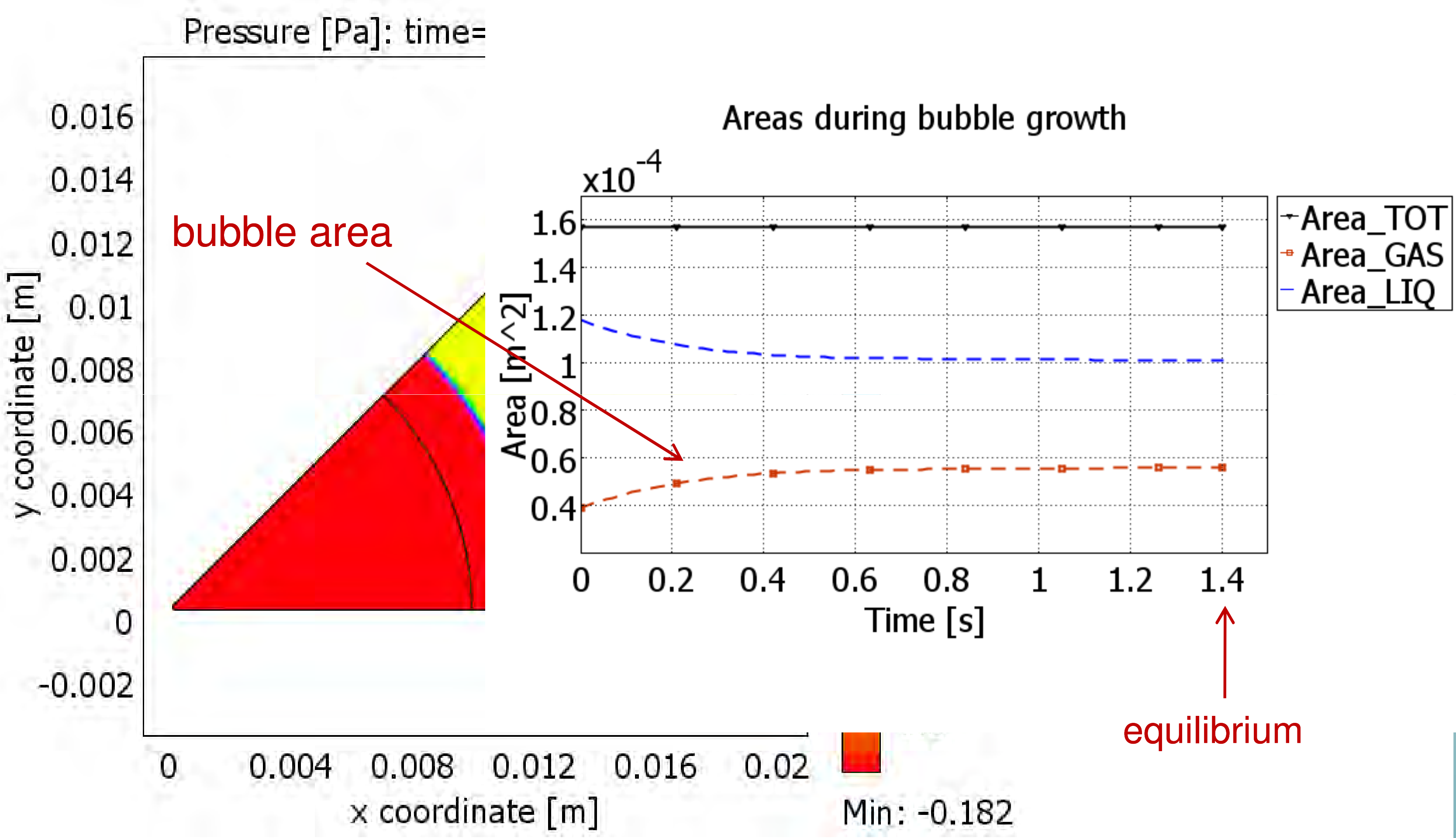


bubble growth

$$R(t=1.4s)=0.012m=R_{eq}$$

$$R_{eq}=\frac{\sigma}{p_G-p_{EXT}}$$

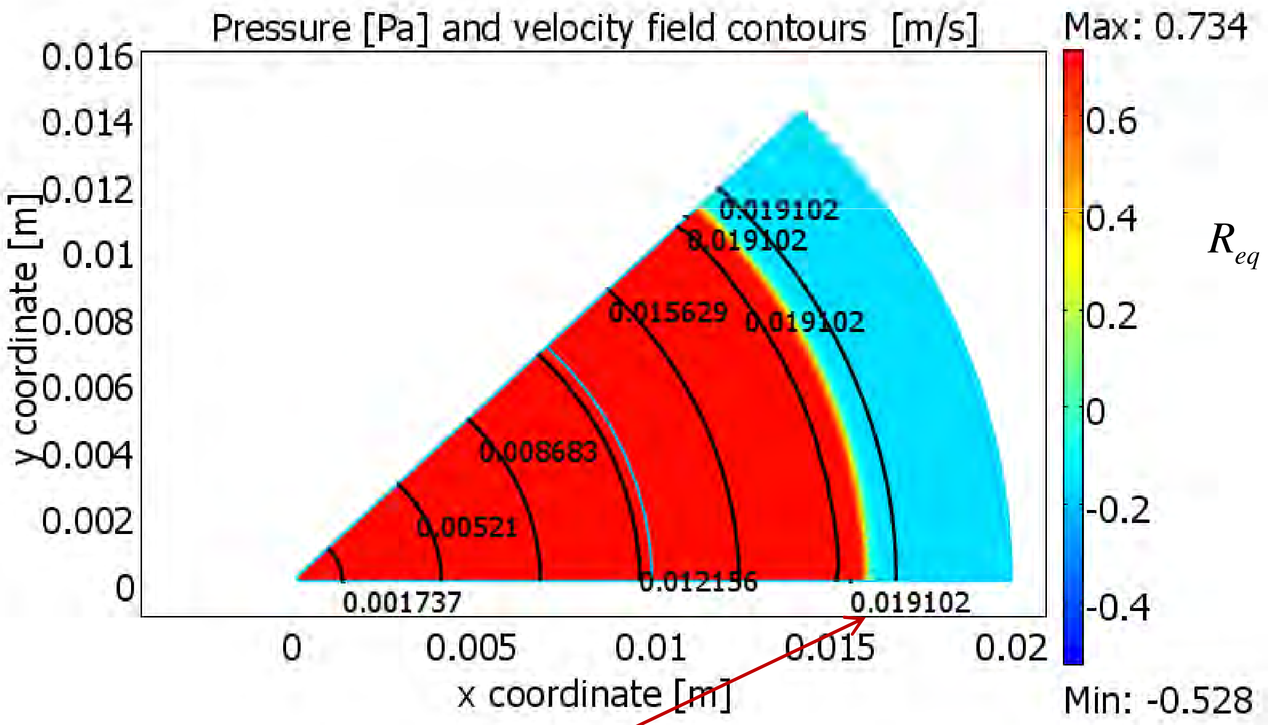
Results


Pressure [Pa]: time=
y coordinate [m]
0.016
0.014
0.012
0.01
0.008
0.006
0.004
0.002
0
-0.002
0
0.004
0.008
0.012
0.016
0.02
x coordinate [m]
Min: -0.182
bubble area
Areas during bubble growth
x10^-4
1.6
1.4
1.2
1
0.8
0.6
0.4
Area [m^2]
0
0.2
0.4
0.6
0.8
1
1.2
1.4
Time [s]
Area_TOT
Area_GAS
Area_LIQ
equilibrium

Results

pressure and velocity contours

$p_{G,0} = 2.2\,\text{Pa},\; t = 0.2\,\text{s}$, bubble is still expanding



$$R_{eq} = \frac{p_{G,0}\, R_0^{\;2}}{\sigma} = 0.022\,m$$

$$R(t = 0.2s) \cong 0.016\,m$$

$$\frac{\sigma}{R_{eq}} \cong 0.45\,\text{Pa} < p(t = 0.2s) \cong 0.73\,\text{Pa}$$

Conclusions

- A Comsol Multiphysics model simulates bubble growth with flow in gas and liquid regions. Gas pressure drives the expansion.
- A weakly-compressible model, coupled to a level set equation, allows to capture the interface. The gas is ideal and surface tension effects are present.
- The model takes into account moderate density and viscosity differences values for the fluids, but it could represent a basis for successive realistic simulations of foam expansions.
- In this sense, for a future work:

  - accurate and larger transient at the beginning of the growth phenomena, together with a denser mesh on interface will be required
  - mass diffusion and heat transfer will be added to the model.

References

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Many thanks for your attention.

Thanks also to the organizers of

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