NUMERICAL SIMULATION OF MICROPOROSITY FORMATION IN A356 ALUMINUM ALLOY

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Current Status of Structural Materials
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A. Bahmani, N. Hatami, N. Varahram, P. Davami, "A Mathematical Model for Prediction of Microporosity Formation in Aluminium Alloy A356", International Journal of Advanced Manufacturing Technology, Vol. 64, pp 1313-1321, 2013,.

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CONTENTS

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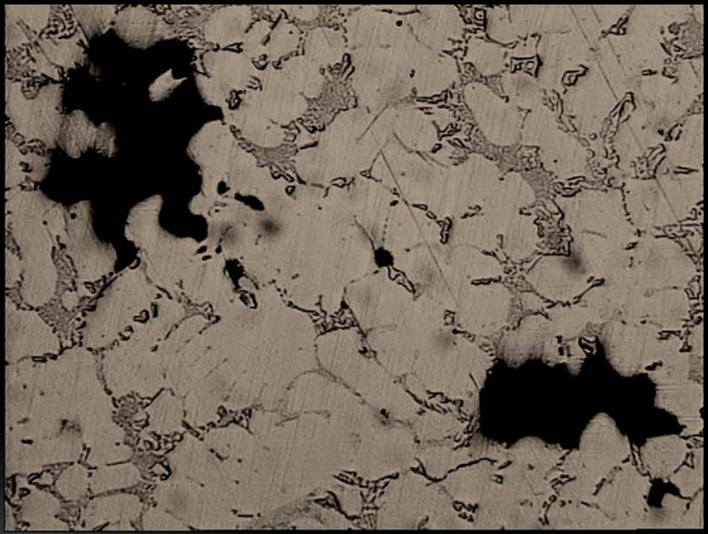

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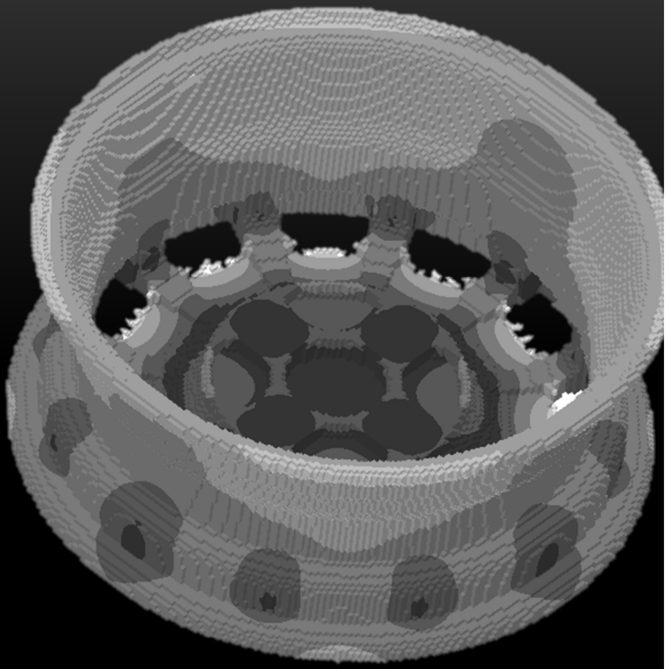
INTRODUCTION

- ***Definitions and Theories***
  - ***Casting, Solidification, Feeding***
  - ***Porosity and its importance***
- ***Numerical Model for Prediction of Microporosities***
  - ***Criteria (Niyama (G/V), Hansen Sahm ($G/t_f^{3/2}$), …)***
  - ***Conservation Equations***
- ***Solution of Heat, Solidification, Continuity and Gas Conservation Equations***
- ***Presentation of a 3D Model to:***
  - ***Solve Pressure Distribution, and Porosity Contents in Interdendritic Region***
  - ***Considering Variant Properties (K, d, Cp, HTC and so on)***
- ***Verification of Model with Experiments***
- ***Coupling with SUTCAST, Commercial Software***



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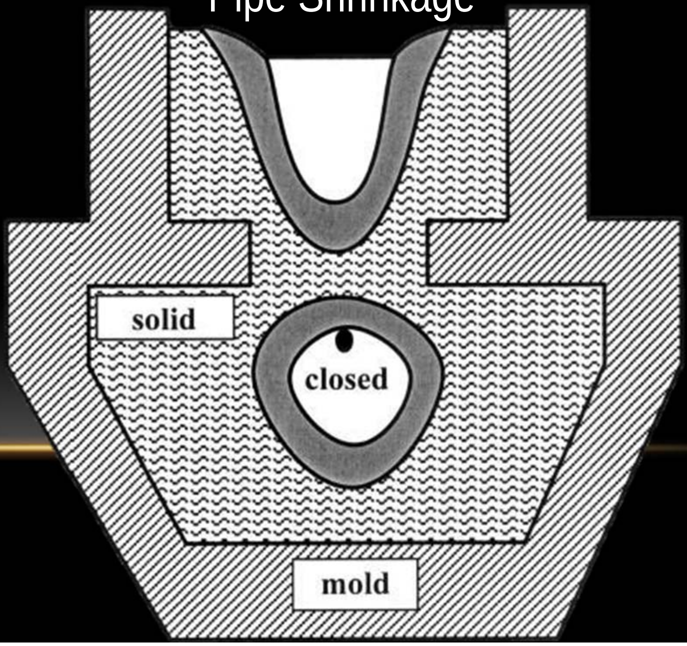
Porosities Classification

- ***Based on Size (Micro and Macro)***
  - ***Microporosities and Microshrinkages***
- ***Based on the Formation Mechanism (Gas and Shrinkage)***



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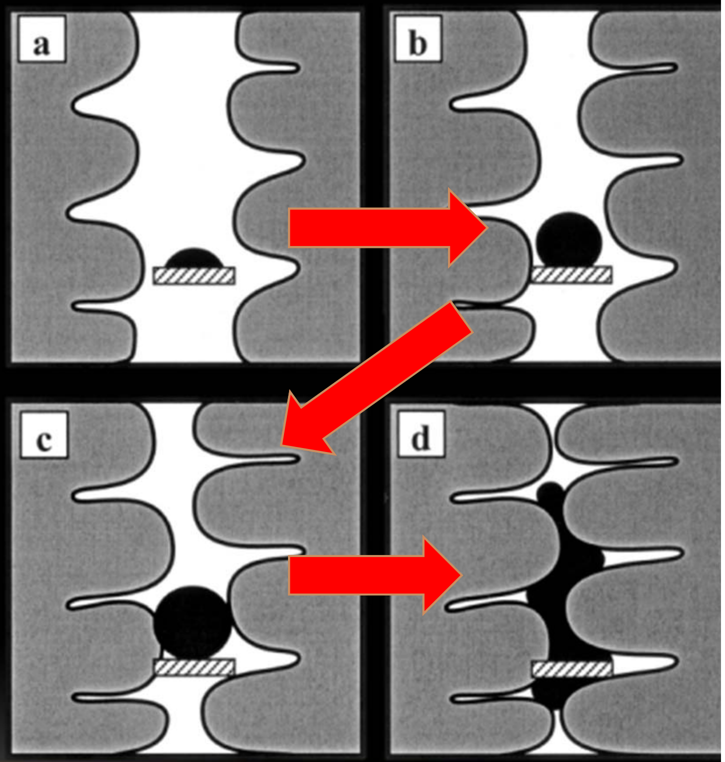
NUCLEATION AND GROWTH

Pores Formation

- *Solidification Shrinkage (Density Change via the Transformation)*
- *Gas Segregation (Solubility Change via the Transformation and Temperature Decrease)*

Level of Growth

- *Heterogenous Nucleation (on Oxides or Inclusions)*
- *Spherical Growth by Gas Diffusion*
- *Growth Limitation by Solidification Front (Dendrites)*
- *Deformation of Pore within Solidification Growth*



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GOVERNING EQUATIONS

- Permeability
- Dendrite Arm Spacing
- Darcy's Equation
- Viscosity
- Hydrogen Solubility
- Gas, Liquid and Surface Tensions Relationship
- Pressure Applied Due to Surface Tension
- Pore Radius

$$K = \frac{1 - g_s^3}{g_s^2} \times \frac{\lambda_2^2}{180}$$

$$\lambda_2 = a t_f^b$$

$$u_l = -\frac{K}{\mu g_l}(\boldsymbol{grad} P_L - \rho_L \boldsymbol{g})$$

$$\mu = \mu_0 \exp(E_\mu / RT)$$

$$[H]_l = K_l \sqrt{P_i}$$

$$P_g = P_l + P_\sigma$$

$$P_\sigma = \frac{2\sigma_{Pl}}{r}$$

$$r = \frac{\lambda_2}{4}$$

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NUMERICAL METHOD

- **Gas Conservation**
- **Continuity**

$$\rho_L[H]_o = \rho_s g_s [H]_s + \rho_L g_L [H]_L + \frac{\alpha g_p P_g}{T}$$

$$\frac{\partial \rho}{\partial t} + div(\rho \mathrm{u}) = 0$$

$$\frac{\partial \overline{\rho}}{\partial t} - \rho_l \frac{\partial g_p}{\partial t} + \rho_1 div\left(-\frac{k}{\mu g_l}(\mathrm{grad}P_l - \rho_l \mathrm{g})\right) = 0$$

Where $\overline{\rho} = \rho_l g_l + \rho_s g_s$

- **Discretized Eq.**

$$g_p{}^n = g_p{}^o + \frac{\overline{\rho}^n - \overline{\rho}^o}{\rho_l} - \rho_l \frac{K\Delta t}{\mu}\left[\frac{P^o{}_{i+1,j,k} + P^o{}_{i-1,j,k} - 2P^o{}_{i,j,k}}{\Delta X^2} + \frac{P^o{}_{i,j+1,k} + P^o{}_{i,j-1,k} - 2P^o{}_{i,j,k}}{\Delta Y^2} + \frac{P^o{}_{i,j,k+1} + P^o{}_{i,j,k-1} - 2P^o{}_{i,j,k}}{\Delta Z^2}\right]$$

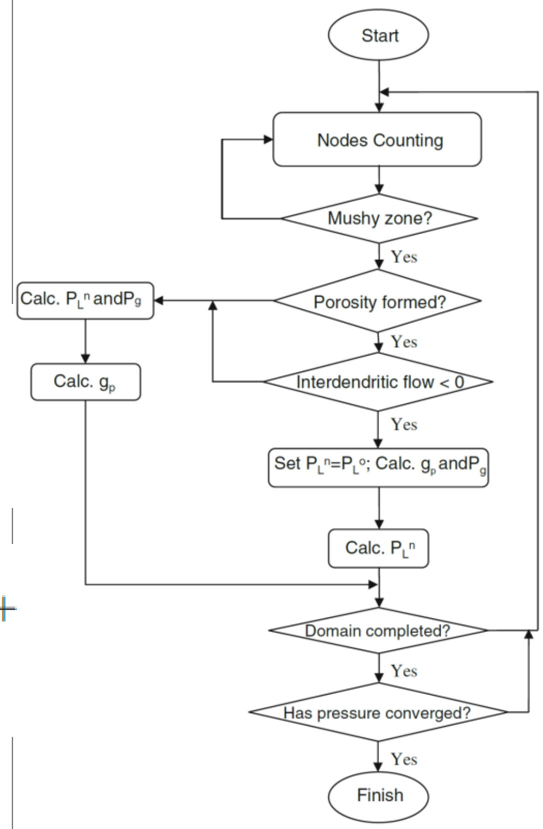

Fig. 2 Flowchart of program for computation of pressure and porosity in each time step

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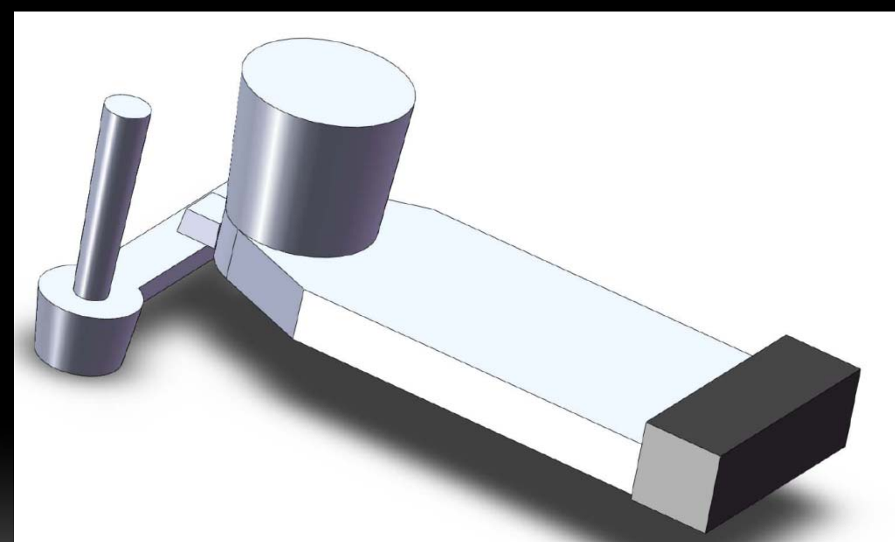
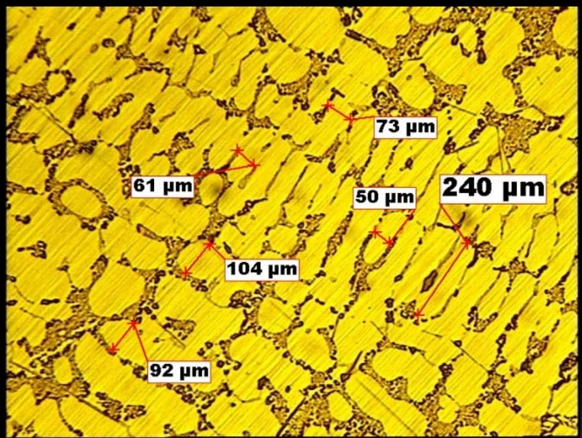
- **Experimental Procedure**
- **Aluminum A356**
- **Steel Chill**
- **Hydrogen Degassing by Rotary Degassing**
- **Gas Measurement by High Scan Measurement Device**
- **Microporosity Measuring by Densitometer (Archimedes Equation)**

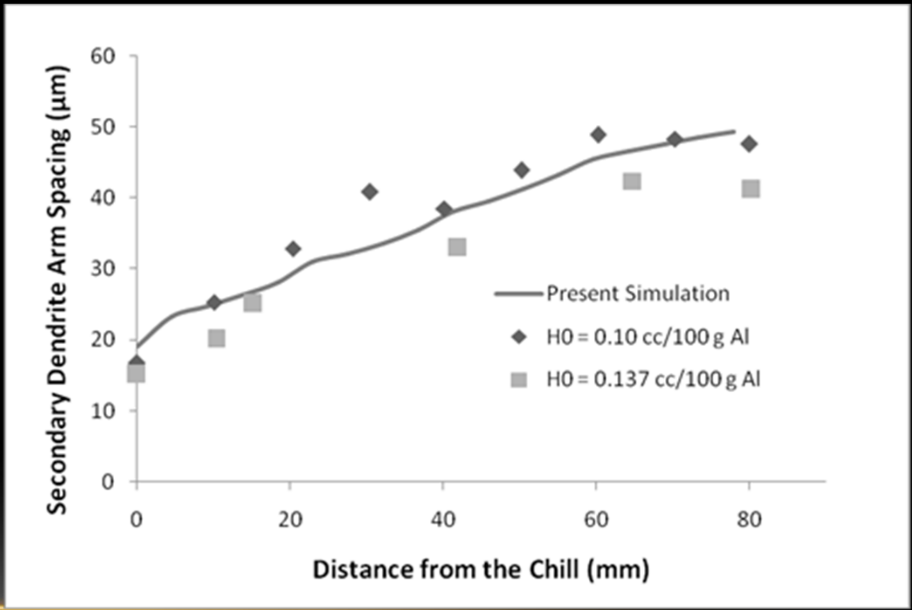


SECONDARY DENDRITE ARM SPACING (SDAD)

✓Good Agreement between the Results

✓ Increase in SDAS by getting Distance from Chill (Decreasing of Cooling Rate)





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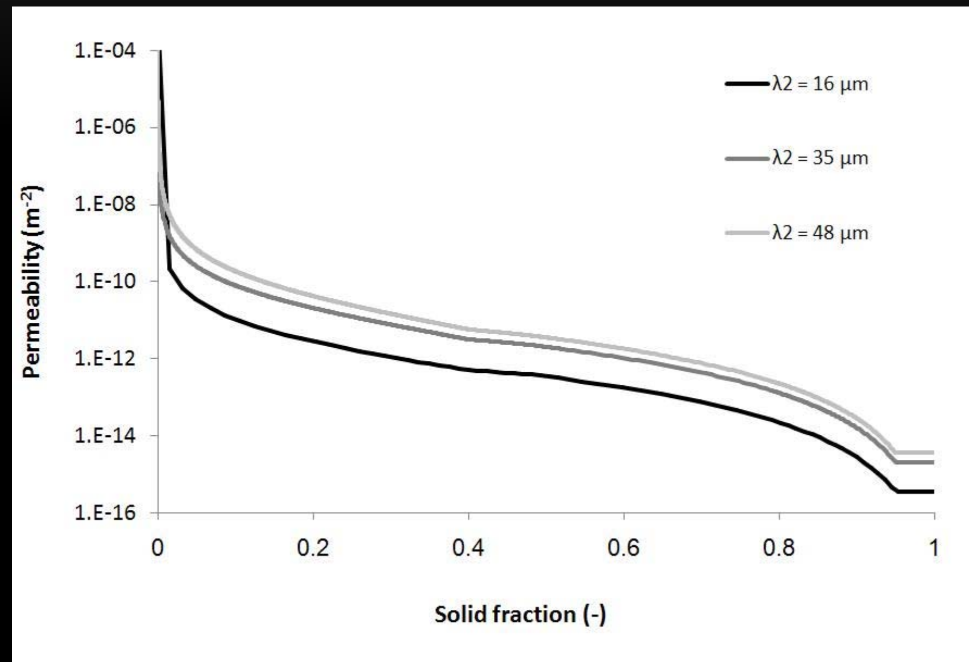
- ***Suddenly Drop of Permeability by Initial formed Dendrites***
- ***Change in the Curvature at Coherency Point***
- ***Lower Permeability for Finer Structures***



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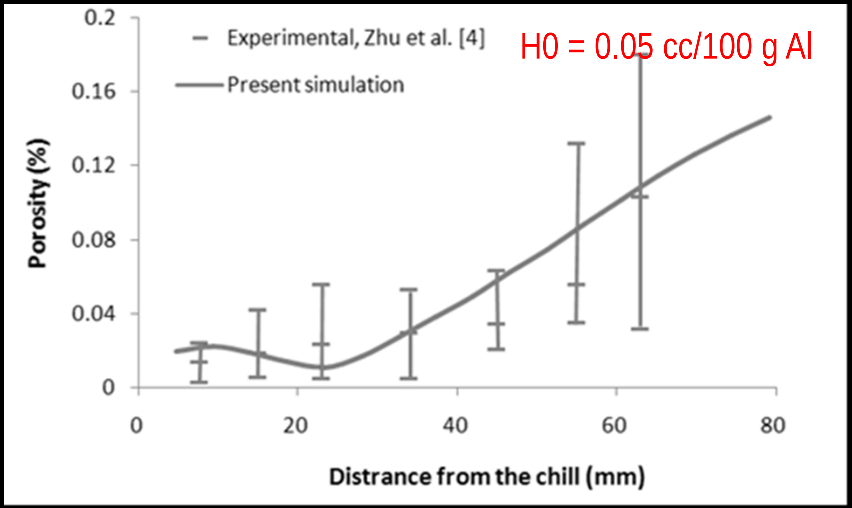
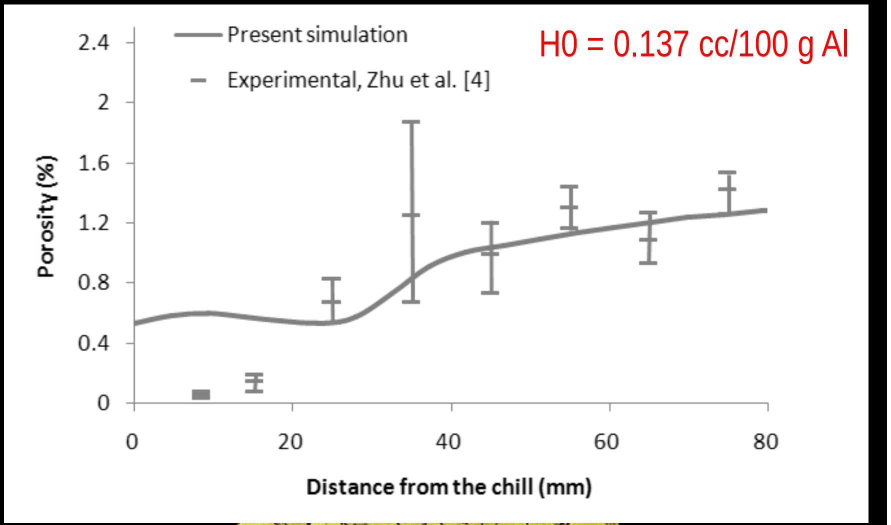
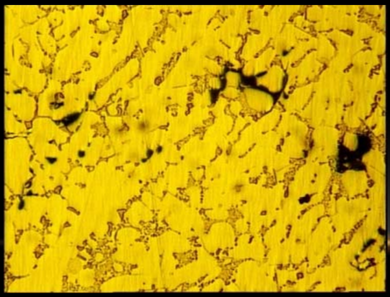
MICROPOROSITY DISTRIBUTION

- ✓More porosities in Regions with Less Cooling Rates
- ✓Good Agreement between Results in Low and High Contents of Gas







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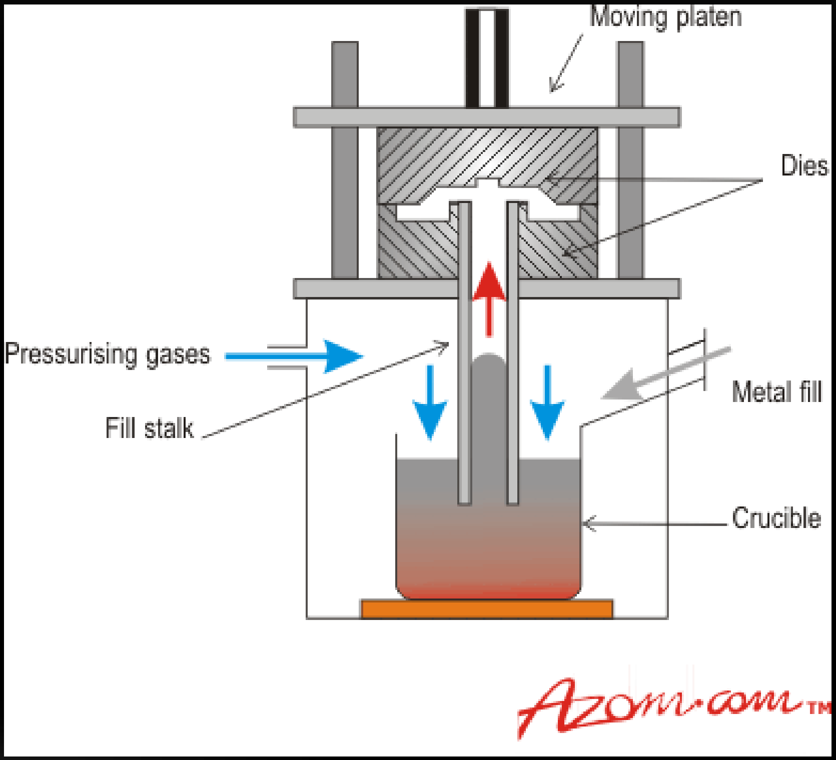
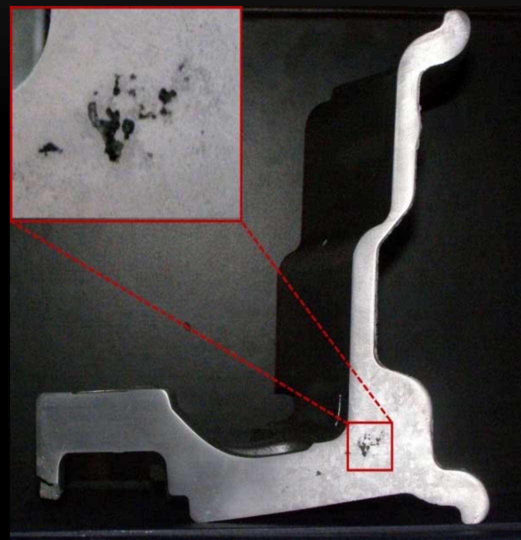
COUPLING WITH SUTCAST SIMULATION SOFTWARE (LOW PRESSURE DIE CASTING)

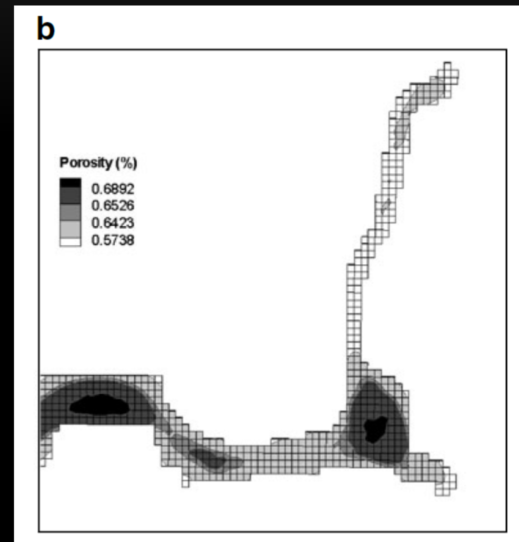
- **Counter Gravity Feeling**
- **High Quality Casting**
- **Expensive Process**

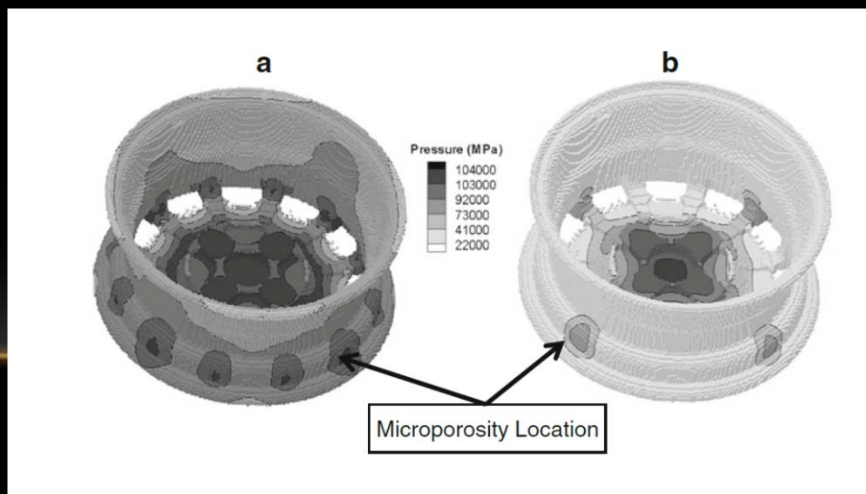


COUPLING WITH SUTCAST SIMULATION SOFTWARE (LOW PRESSURE DIE CASTING)

- Microporosity and Feeding Behavior Prediction for Industrial Castings







CONCLUSIONS

- ***Proportionally Good Agreements between Results***
- ***Solidification development makes the metal more complex and more difficult to feed***
- ***Increasing of cooling rate make the structure finer and resistance of solid domain increases but anyway there is less time in this regions for pore's growth.***
- ***In lower values of cooling rate more porosities observed which is related to the diffusion of gas and shrinkage growth.***
- ***The Model combined with SUTCAST simulation software and examined successfully in an industrial casting.***

THANKS FOR YOUR ATTENTION