Mold-flow Simulation in 3 Die Stack Chip Scale Packaging

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(Amkor Technology/Korea)

Mold-Flow Simulation in 3 Die Stack CSP of mold array packaging with different Gate types

ISMP 2005

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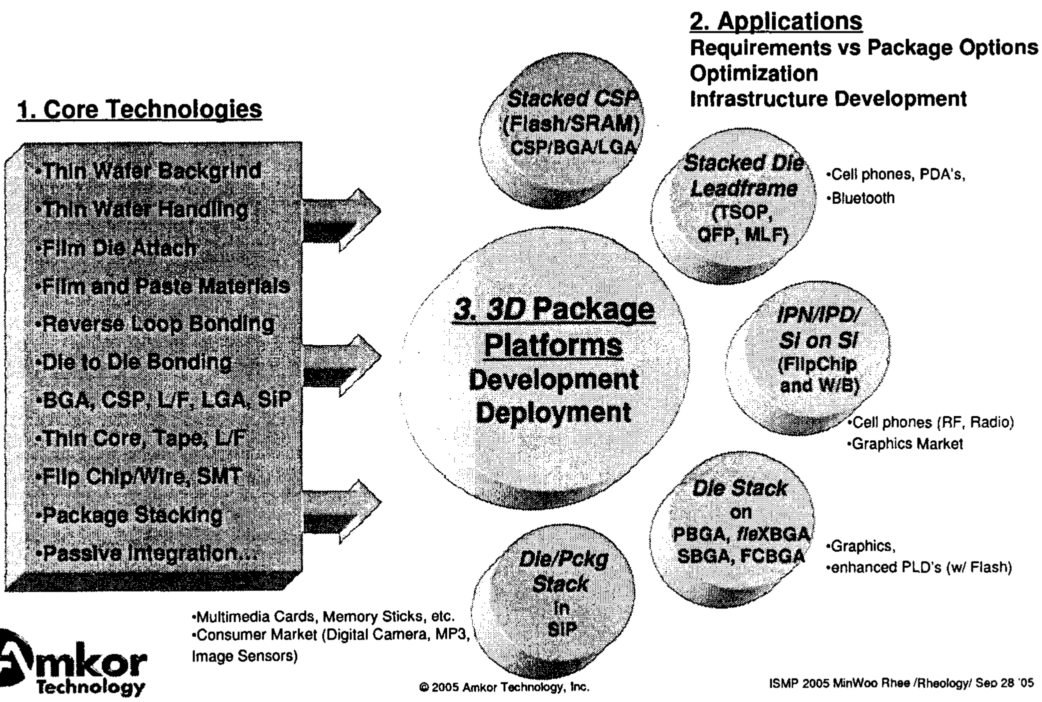
3D Packaging Strategy



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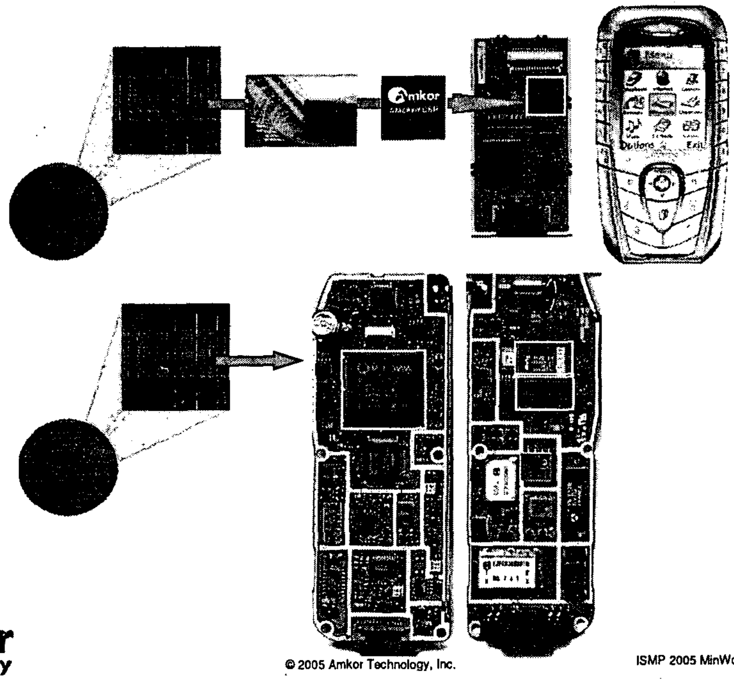
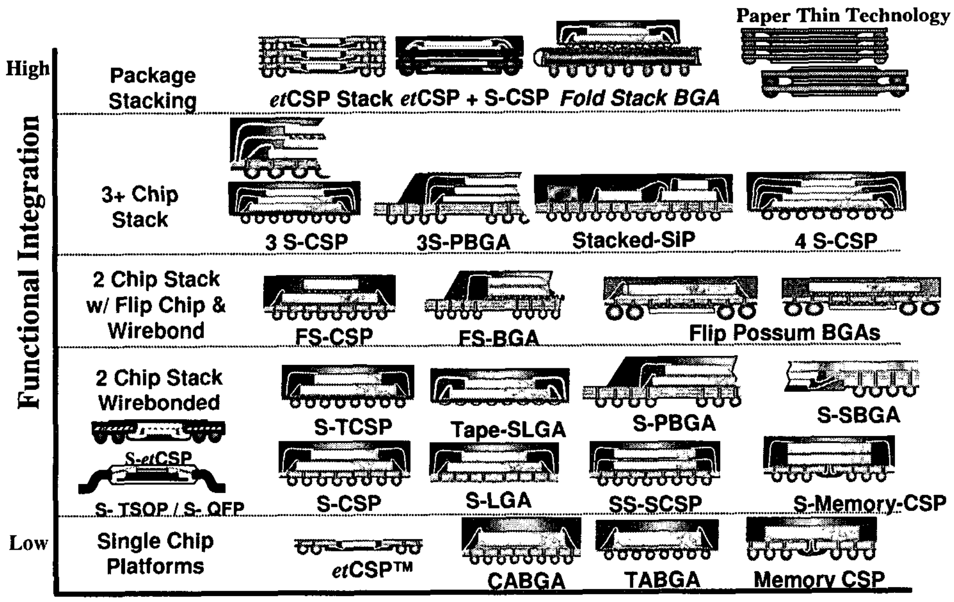
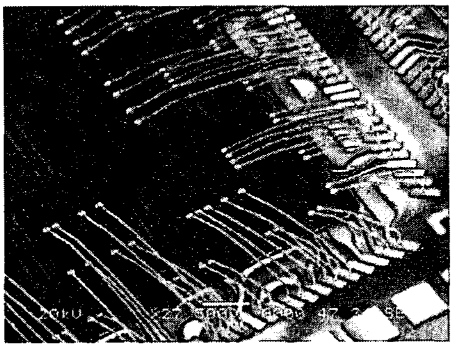
3D Packaging Strategy

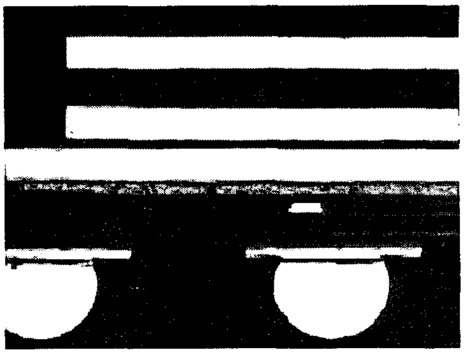


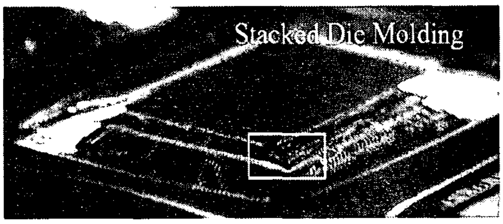
3D Packaging Platforms

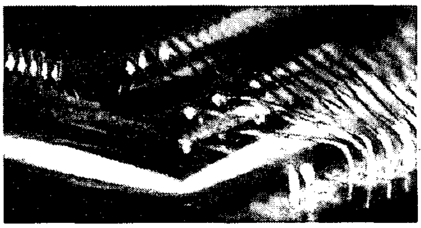


Multi-Die stacking Structure









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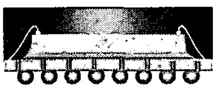
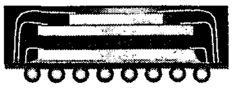
Mold Challenges in Multi Die Stack CSP

Challenges of Mold process of Multi-die stacking structures with thin and high density packaging

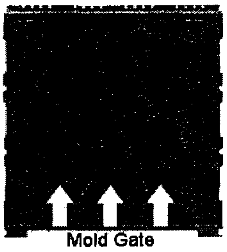
- Mold void
- Weld line of mold
- Incomplete mold
- Exposed wires
- Wire sweeping issues
- Narrow space between die top and mold surface
- Mold flow pattern variance due to higher wiring density.
- Effect of complex geometry of components



CABGA

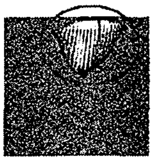


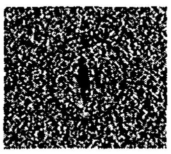
3 die Stack CSP

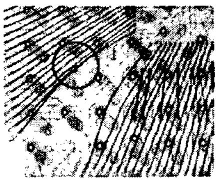


Mold Gate

External void on package surface, induced from incomplete mold flow during process







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Mold Challenges in Multi Die Stack CSP

The Complex chemo-rheology of the thermosetting EMC

- highly Filled silica suspension (80~90 wt%)
- short gelation time (20~30s)
- viscoelastic flow characteristics
- non-linear, multi behavior

Complex geometries

- Molded-in (multi-)silicon chip
- High density connecting wires
- Thin mold gap
- Array mold type
- Components

Pose problems as follows

- incomplete mold
- internal voids
- wire sweeping
- paddle shift
- product design
- material selection
- optimal tool design
- process control.

The urgent requirement is the shift from Trial and Error method to Optimized Rheokinetic model

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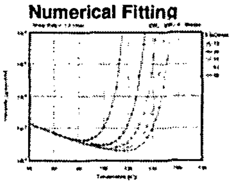
Modeling of 3 die stack CSP with Different gate type – The Procedure

Rheokinetic Properties Determination

Numerical Fitting



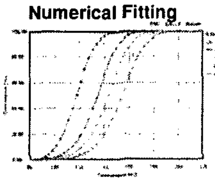
Rheological properties Measured by Rheometer

- shear rate dependency
- isothermal temperature sweep
- dynamic temperature sweep

Cure kinetic properties Measured by DSC

- isothermal temperature sweep
- dynamic temperature sweep

Numerical Fitting



Constitutive relation - Rheology Cross Castro Macosko's relation

$$\eta(T,\dot{\gamma},\alpha)=\frac{\eta_0(T)}{1+\left(\frac{\eta_0(T)\dot{\gamma}}{\tau^*}\right)^{1-n}}\left(\frac{\alpha_g}{\alpha_g-\alpha}\right)^{C_1+C_2\alpha}$$

$$\eta_0(T)=B\exp\left(\frac{T_b}{T}\right)$$

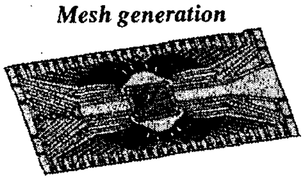
Constitutive relation-Cure kinetics Kamal's equation

$$\frac{d\alpha}{dt}=(k_1+k_2\alpha^m)(1-\alpha)^n$$

$$k_1=A_1\exp(-E_1/T)$$

$$k_2=A_2\exp(-E_2/T)$$

Geometry and Mesh generation



CFD solver algorithm

Governing equation – Fluid motion Navier-Stokes equation.

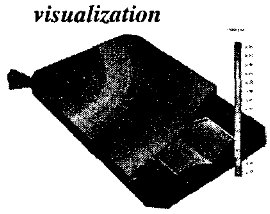
$$\frac{\partial}{\partial t}(\rho\vec{u})+\nabla\cdot\rho\vec{u}\vec{u}=-\nabla p+\nabla\cdot(\eta\,\dot{\bar{\gamma}})+\rho\vec{g}$$

$$\frac{\partial}{\partial t}(\rho C_pT)+\nabla\cdot(\rho C_pT\vec{u})-k\nabla^2T=\eta\dot{\bar{\gamma}}^2+\frac{d\alpha}{dt}\Delta H$$

$$\frac{\partial\rho}{\partial t}+\nabla\cdot\rho\vec{u}=0$$

$$\nabla\cdot\rho\vec{u}=0$$

Calculation and visualization



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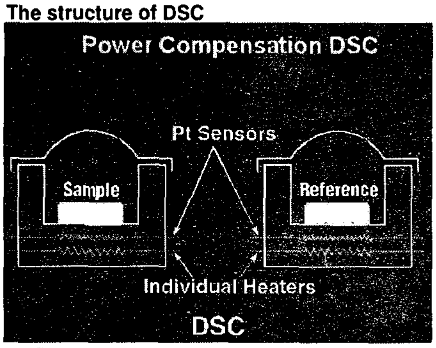
Rheokinetic analysis of commercial EMC

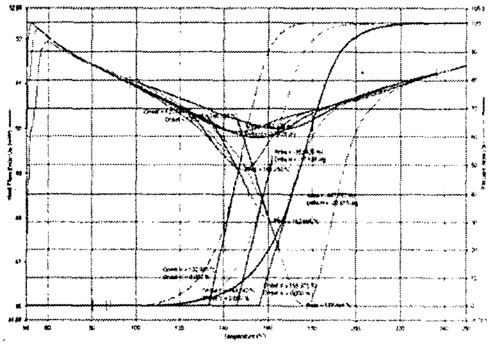
Thermal Analysis to investigate cure behavior of commercial EMC

- **A Differential Scanning Calorimeter (DSC) measures the amount of energy (heat) absorbed or released by a sample as it is heated, cooled or held at a constant (isothermal) temperature.**
- **Provide Cure kinetic information of EMC for viscoelastic flow characterization.**
- **DSC experiment at 5, 10, 20'C/min heating rate were performed**

The structure of DSC



Perkin Elmer DSC 7
dynamic DSC with 5,10,20'C/min heating rate



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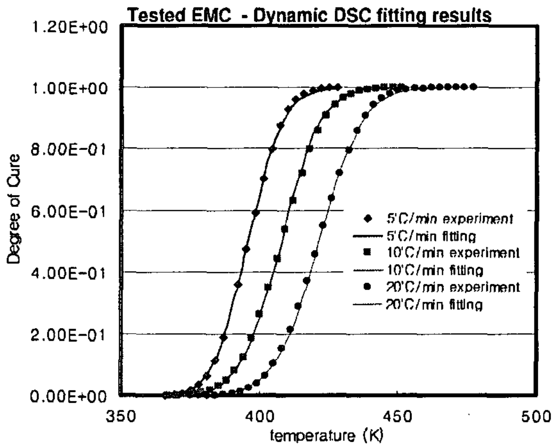
Rheokinetic analysis of commercial EMC

Cure conversion Numerical Fitting results of commercial EMC

- ***The experimental data of commercial EMCs of cure conversion (0.0< α < 1.0) are fitted by best fitting numerical parameters.***
- ***The data points are the experimental data and the solid line is the fitted model equation for 5, 10, 20°C temperature ramping rates.***



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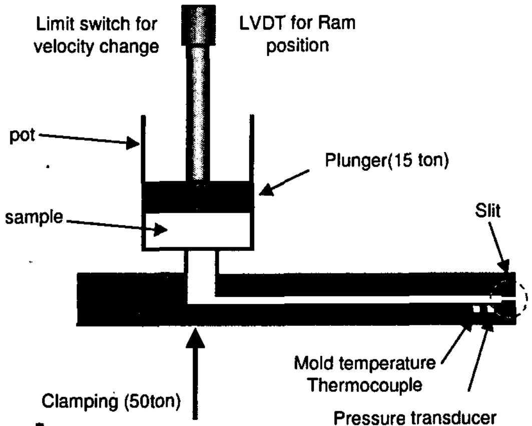
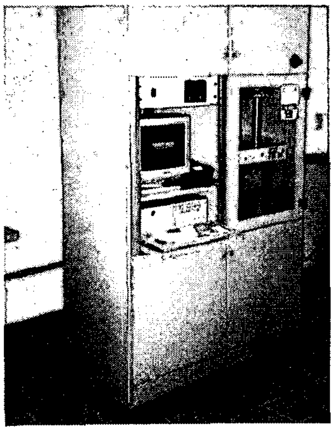
Rheokinetic analysis of commercial EMC

Slit Die Rheometry for moderate shear rate experiment

- **Measure the viscosity of epoxy molding compounds at processing conditions (160~180C) where the viscosity changes very rapidly with time.**
- **A slit of small rectangular cross-section was chosen. Heating the sample through in a thin disk-shaped reservoir upstream of the slit.**
- **Sensor detects the pressure drop and calculates the viscosity values**



Slit Die Rheometry supported by Chell Industry.



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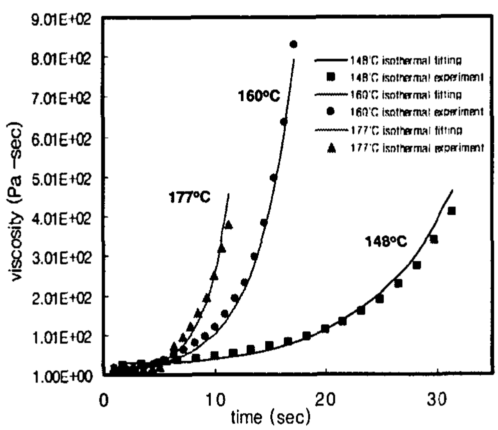
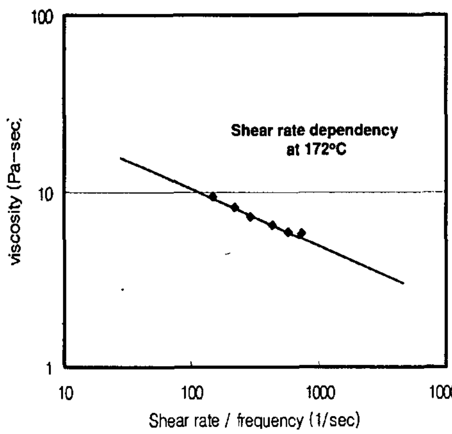
Rheokinetic analysis of commercial EMC

Rheokinetic Numerical Fitting results of commercial EMC

- **148, 160, 177°C isothermal viscosity fitting results by Cross Castro Macosko's Model.**
- **The shear rate dependency at 172 °C of tested EMC showed.**





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Rheokinetic analysis of commercial EMC

Acquired Numerical Estimated Parameters for Rheokinetic model

Constitutive relation-Cure kinetics
Kamal's equation

$$\frac{d\alpha}{dt} = (k_1 + k_2\alpha^m)(1-\alpha)^n$$

$$k_1 = A_1 \exp(-E_1/T)$$

$$k_2 = A_2 \exp(-E_2/T)$$

Constitutive relation - Rheology
Cross Castro Macosko's relation

$$\eta(T, \dot{\gamma}, \alpha) = \frac{\eta_0(T)}{1+\left(\frac{\eta_0(T)\dot{\gamma}}{\tau^*}\right)^{1-n}} \left(\frac{\alpha_g}{\alpha_g - \alpha}\right)^{c_1 + c_2\alpha}$$

$$\eta_0(T) = B \exp\left(\frac{T_b}{T}\right)$$

Fitted Curing Kinetics Parameters	
m	0.598798
n	0.995103
A1	7.09E+09
A2	1.91E+07
E1 (K)	13658.1
E2 (K)	8827.04
H	0
Fitting Error	0.488165

Fitted Viscosity Parameters	
n	7.23E-01
tau (Pa)	0.0001
B (Pa-s)	0.00292085
Tb (K)	6393.58
C1	0.940095
C2	10.9996
ag	0.115368
Fitting Error	0.462298

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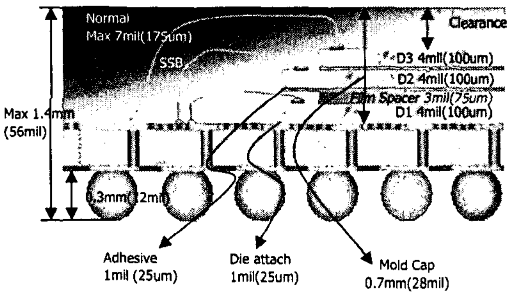
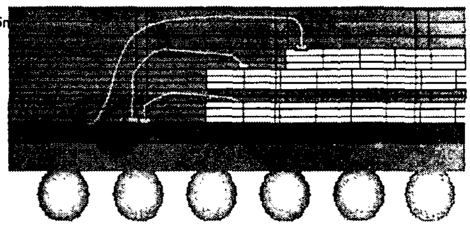
Geometry and Mesh generation

Package structure of 3 die stacking

- The package structure of the 3 die stacking with 4x4 mold array was generated as the standard structure based on AutoCAD drawings.
- The z-directional mesh is divided as 3 for each die area, and spacer is divided by 2.
- The mold gap between die surface and mold top was divided by 3 meshes.
- The total z directional number of stacking is 14.





Simulated package structure

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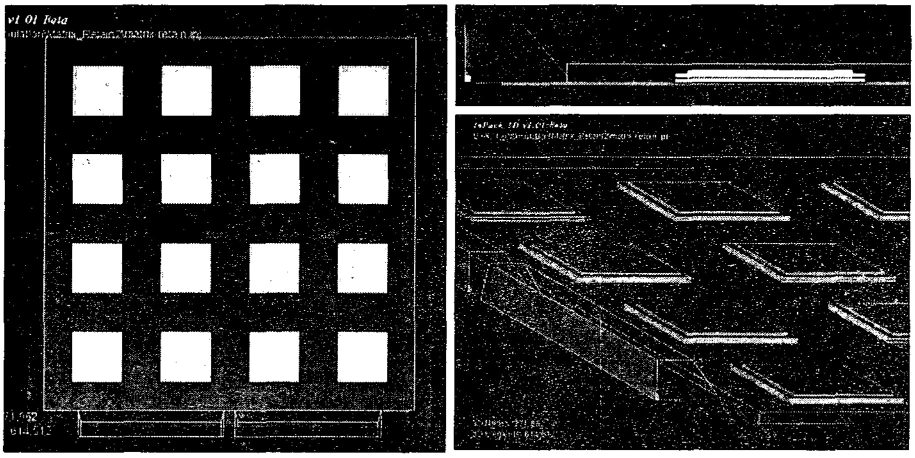
Geometry and Mesh generation

Package structure of 3 die stacking with 4x4 mold array

- Solid package structure of the 4x4 mold array type for current modeling shown as below (center gate design).



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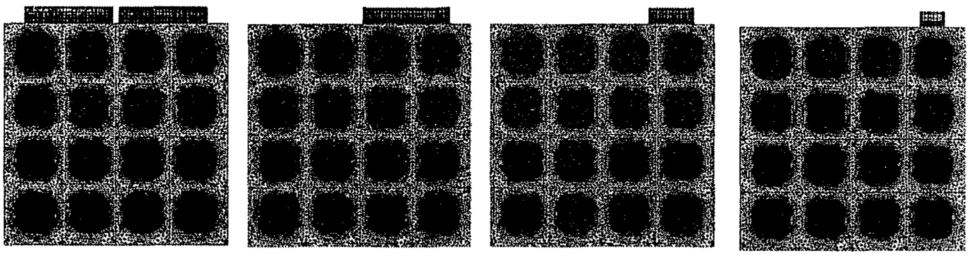
Geometry and Mesh generation

Mesh generation for 4 kinds of gate type and mold cavity for current modeling

- Total number of mesh used for full 3D model : 3 die SCSP is 660,000
- The transfer time was 7.4 sec with optimum ram position control.
- The used estimated material information for rheokinetic evaluation

Center gate | Half gate | Quarter gate | Corner-gate



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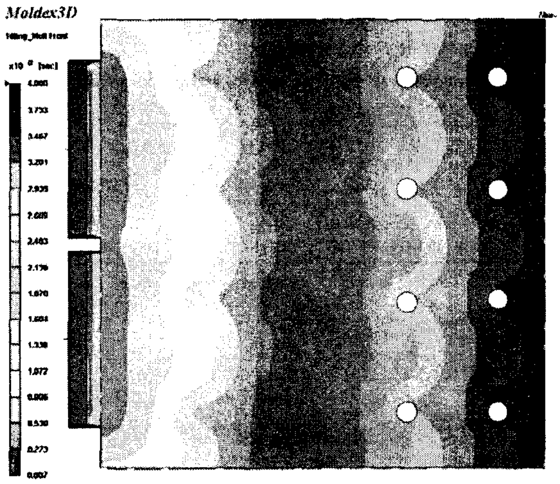
Mold filling pattern results

Melt front filling time contour : Center-gate

- The melt front shows parallel to the gate and the flow is influenced by the stacked die.
- The reduced flow speed of stacked structure area induced the void trapping phenomena along the final filling area of package edge



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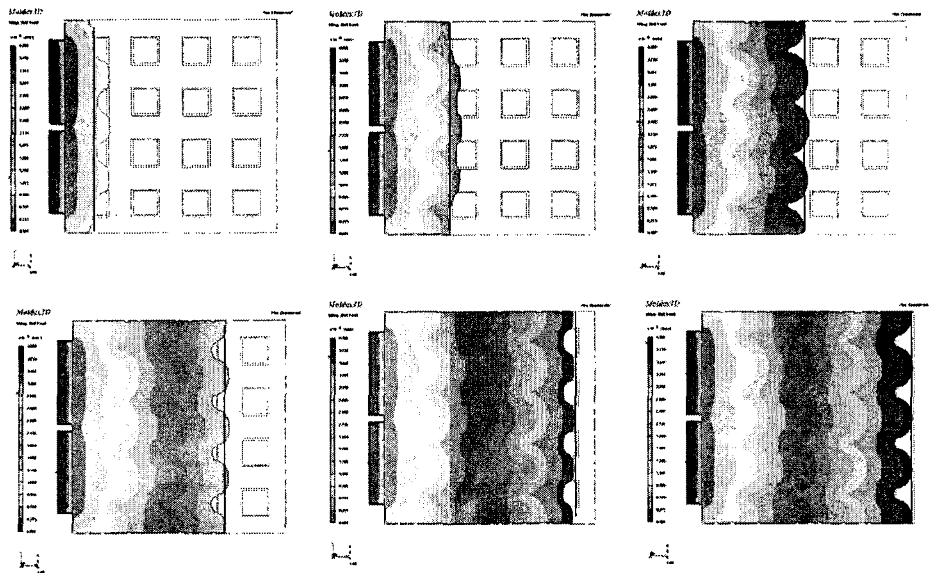
Mold filling pattern results

Melt front filling time contour : Center-gate



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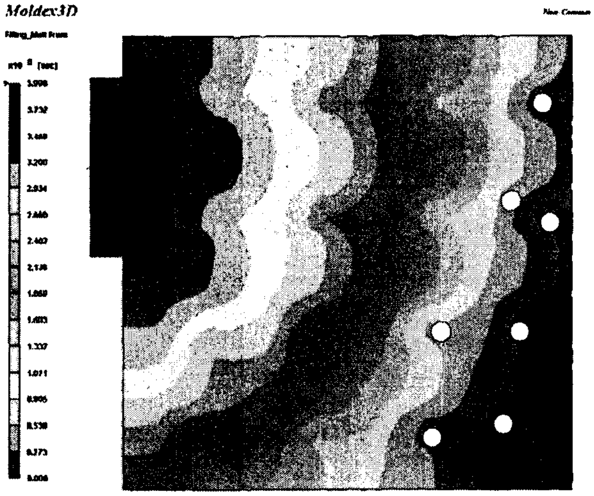
Mold filling pattern results

Melt front filling time contour : Half-gate

- To resolve the void trapping along the opposite side of the gate near package edge, the half of the standard center gate is applied as shown below.
- The void trapping zone is slightly moved to corner of the package.



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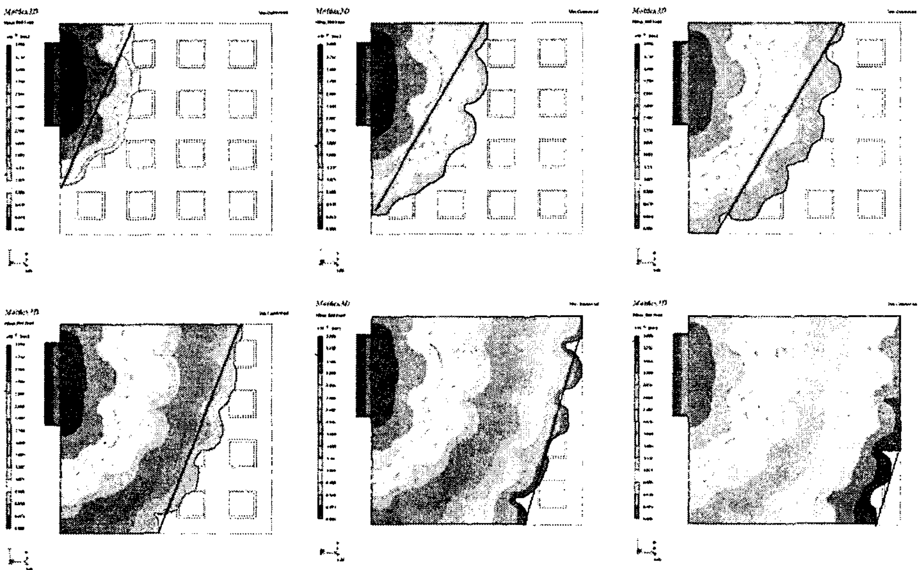
Mold filling pattern results

Melt front filling time contour : Half-gate



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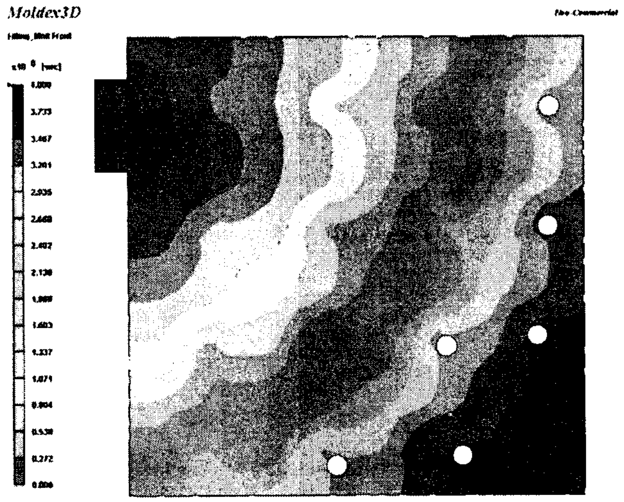
Mold filling pattern results

Melt front filling time contour : Quarter-gate

- The quarter of the standard center gate is applied as shown below.
- The void trapping zone is gradually changed as diagonal distribution



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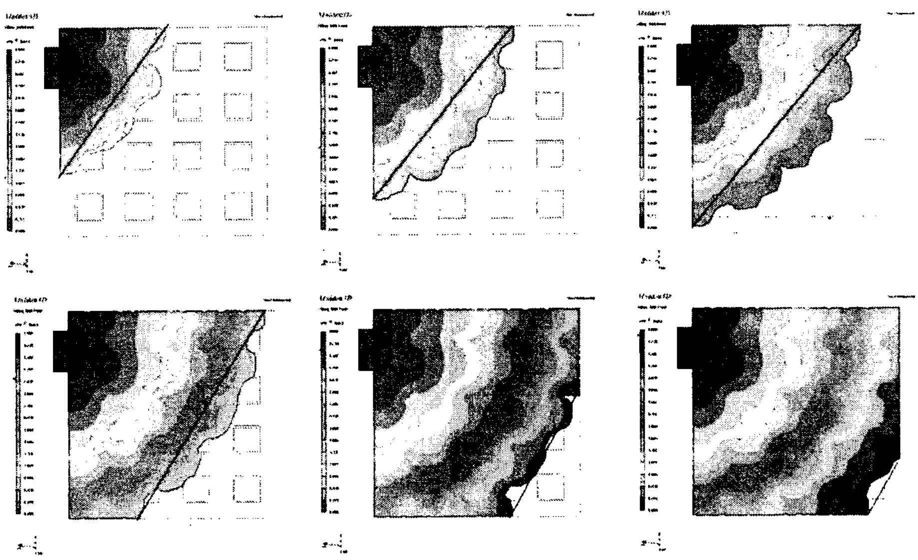
Mold filling pattern results

Melt front filling time contour : Quarter-gate



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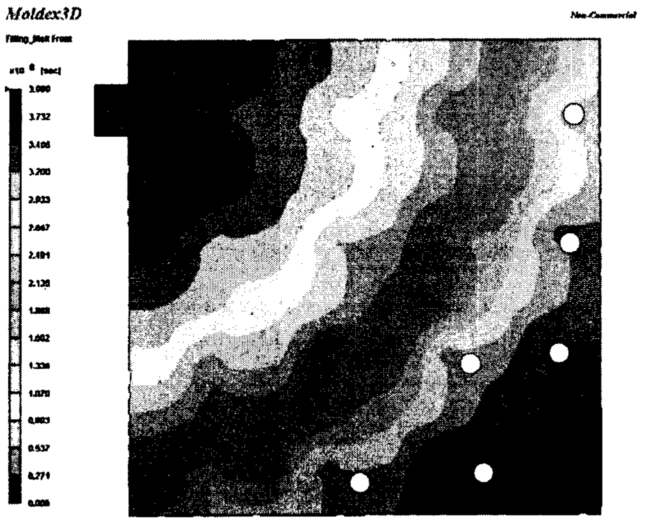
Mold filling pattern results

Melt front filling time contour : Corner-gate

- The corner gate of the standard center gate is applied as shown below.
- The void trapping zone distribution is almost same as quarter gate case.



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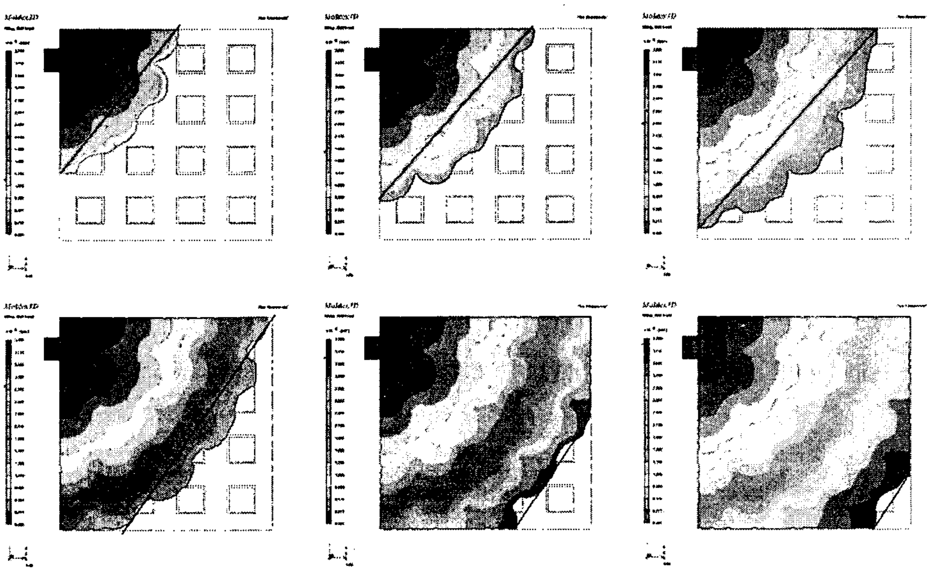
Mold filling pattern results

Melt front filling time contour : Corner-gate



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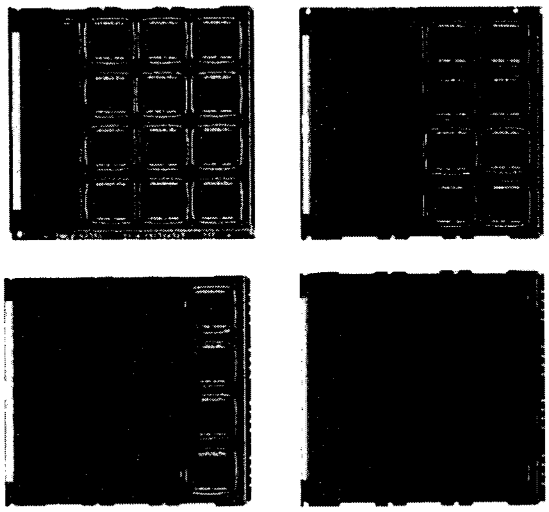
Mold filling pattern –Experimental results

Short shot of the actual Mold flow : Center-gate



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Mold filling pattern –Experimental results

Short shot of the actual Mold flow : Corner-gate

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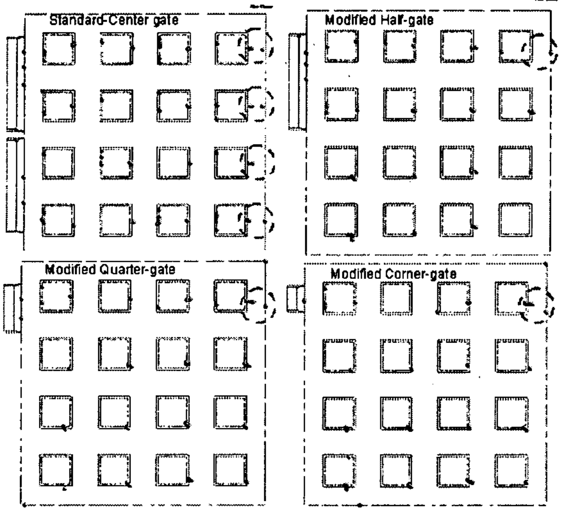
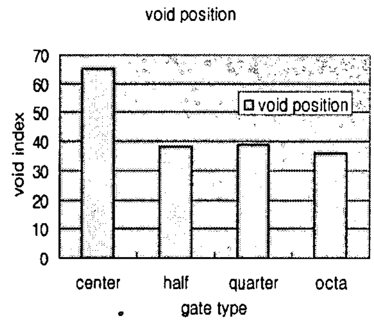
Mold Void Occurrence Comparison

- Trapping results is the numerical prediction of the void index
- Center gate type of the mold array design showed most severe void.
- But other cases (Half, Quarter, Corner) are almost same

Possible mold void trapping phenomena occurring area





gate shape	void position
center	65
half	38
quarter	39
octa	36

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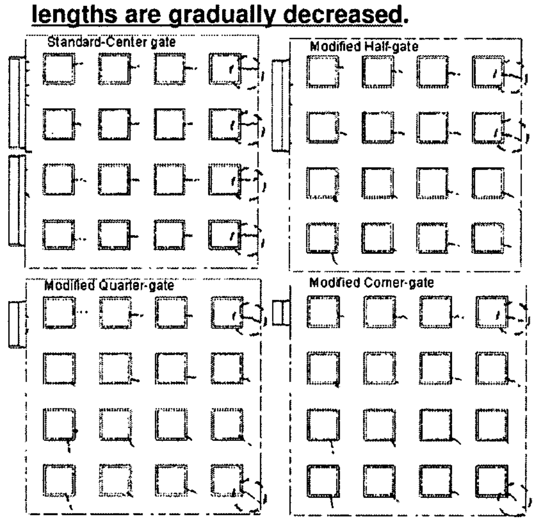
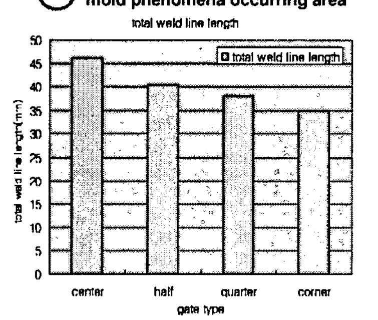
Weld-line Occurrence Comparison

- The weld line is the merging line of the different melt fronts.
- The void or incomplete mold phenomena is quite concern with this weld line length.
- As the gate type is changed from center to corner the total weld line lengths are gradually decreased.

Possible incomplete mold phenomena occurring area





gate shape	total weld line length
center	46
half	40.5
quarter	38
corner	35

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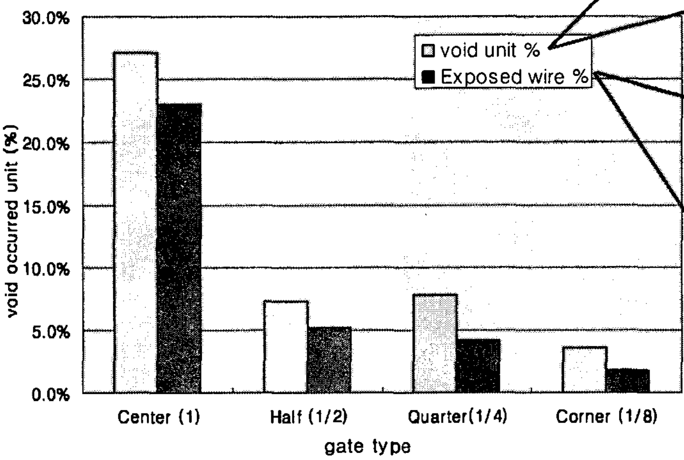
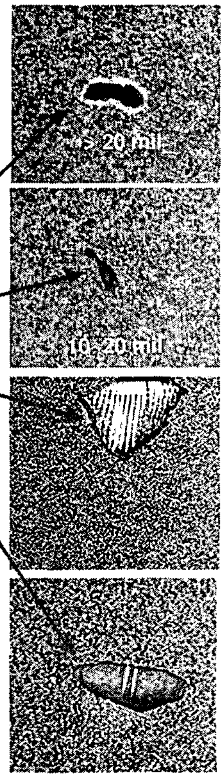
Experimental mold void results

Void performance comparison:

- The Center gate showed Worst performance as expected
- Other cases (Half, Quarter, Corner) are almost same
- Matches well with the Mold-filling simulation results.





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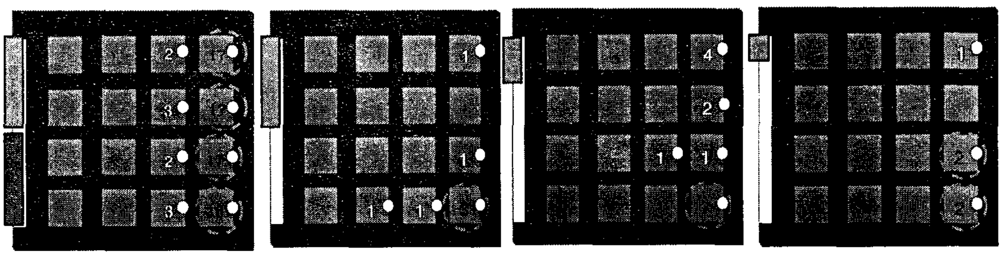
Experimental mold void results

Void positional dependencies comparison

- The void position of Center gate type showed Parallel to the gate direction
- Other cases (Half, Quarter, Corner) showed diagonally opposite position from the gate.
- The distribution of void is closely related with the final filling flow pattern



Gate Design	Total Q'ty	Void performance			
		Total Void	Exposed Wire	void unit %	Exposed wire %
Center (1)	218	59	50	27.1%	22.9%
Half (1/2)	96	7	5	7.3%	5.2%
Quarter(1/4)	192	15	8	7.8%	4.2%
Corner (1/8)	112	4	2	3.6%	1.8%

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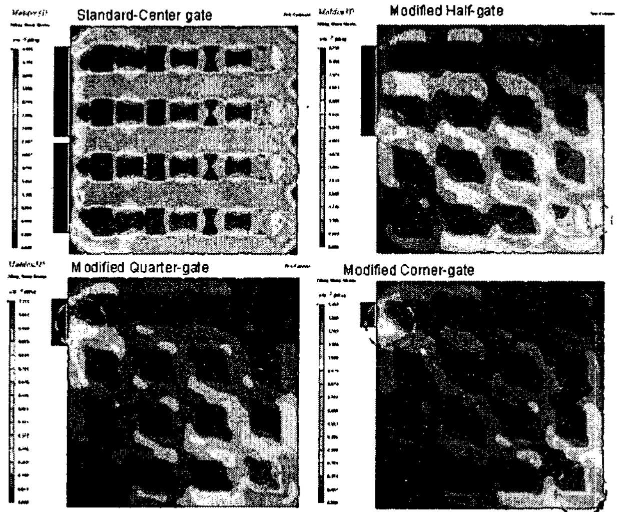
Shear-Stress distribution

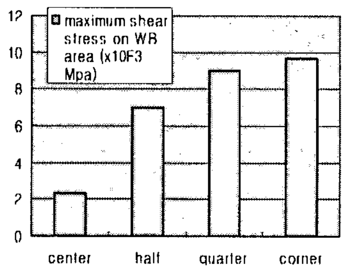
Shear-stress field of final filling stage (package top view)

- The Center gate showed relatively homogeneous shear stress field.
- As the gate size become small, stress near the flow inlet and out net is increased, which may affect severe wire sweeping.



Max shear-stress region

maximum shear stress on WB area (x10F3 Mpa)



gate shape	maximum shear stress on WB area (x10F3 Mpa)
center	2.3295
half	6.991
quarter	8.983
corner	9.71

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Cure conversion distribution

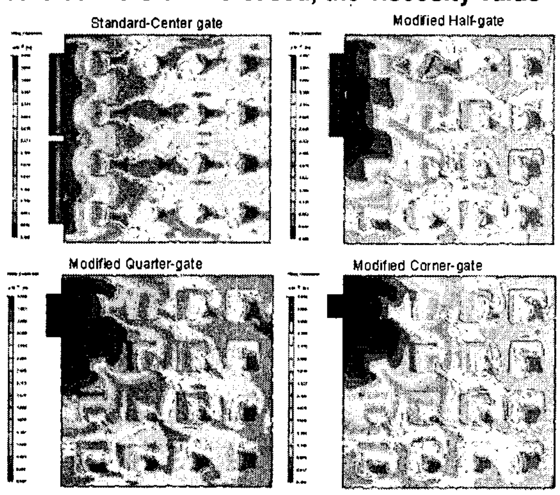
Cure conversion field of final filling stage (package top view)

- The center gate showed parallel to the gate inlet flow direction. As the gate is changed as center to corner, the cure conversion contour changed as diagonal symmetry.
- The cure conversion at the final filling stage is about 4% (0.04)
- As the residence time and cure conversion increased, the viscosity value will also increased.

Constitutive relation - Rheology
Cross Castro Macosko's relation

$$\eta(T,\dot{\gamma},\alpha)=\frac{\eta_0(T)}{1+\left(\frac{\eta_0(T)\dot{\gamma}}{\tau^*}\right)^{1-n}}\left(\frac{\alpha_g}{\alpha_g-\alpha}\right)^{c_1+c_2\alpha}$$

$$\eta_0(T)=B\exp\left(\frac{T_b}{T}\right)$$



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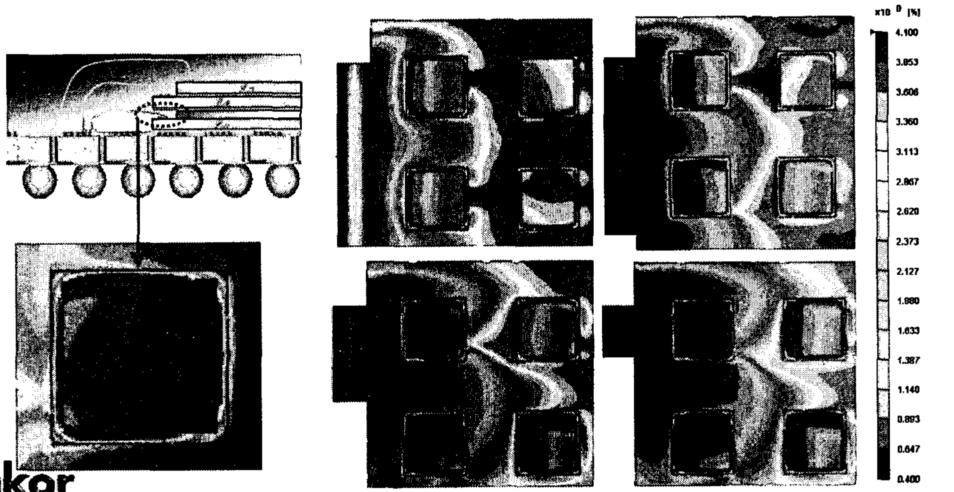
Cure conversion distribution

Cure conversion field of final filling stage (Stacked cavity region)

- The stacked cavity structure of same die stacking area showed relatively high conversion contour value (4%)
- Mold flow in cavity region are expected to be flows slowly which means it will have longer residence time, high conversion & viscosity value.



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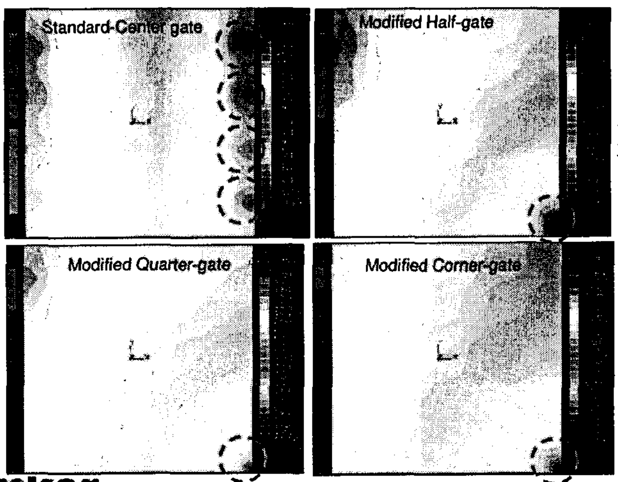
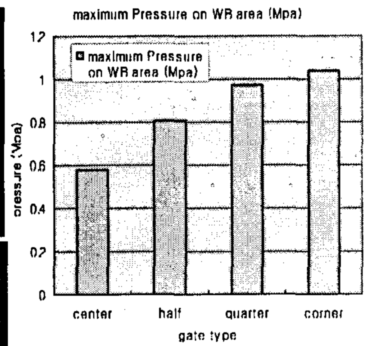
Pressure Field distribution

Mold pressure field of final filling stage (package top view)

- The pressure value of the molten EMC (package top) is increased near gate as the gate type changed from center gate to corner gates.
- The low pressure area and the void occurring area showed similar position.





gate shape	maximum Pressure on WB area (Mpa)
center	0.58
half	0.807
quarter	0.972
corner	1.04

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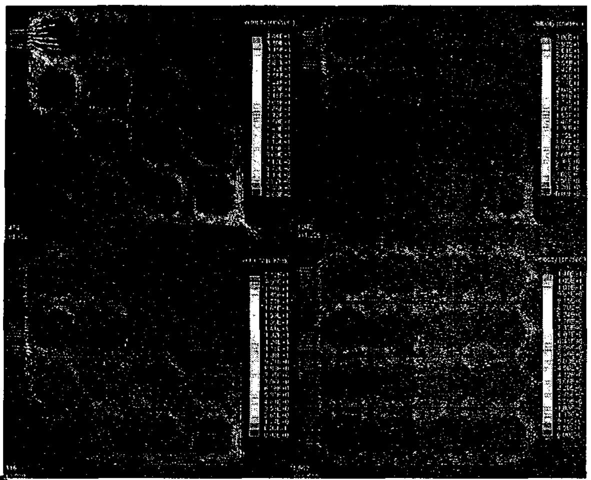
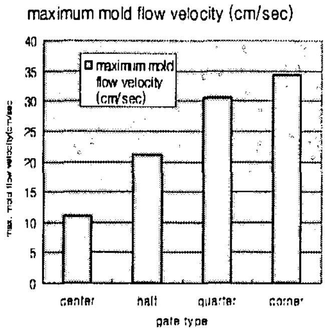
Velocity Field distribution

Mold flow velocity field of final filling stage (package top view)

- **The mold flow velocity is highly increased near the gate and outlet as the gate type is changed from center gate to corner gate.**
- **For the corner gate this unbalanced velocity distribution caused the severe wire sweeping near gate and final mold filling zone.**





gate shape	maximum mold flow velocity (cm/sec)
center	11
half	21.2
quarter	30.6
corner	34.4

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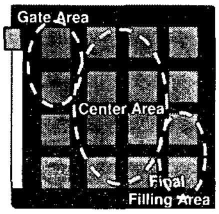
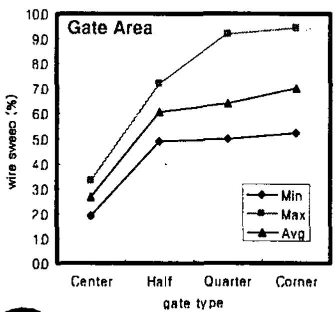
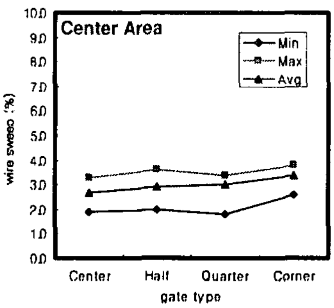
Experiment : Wire Sweeping

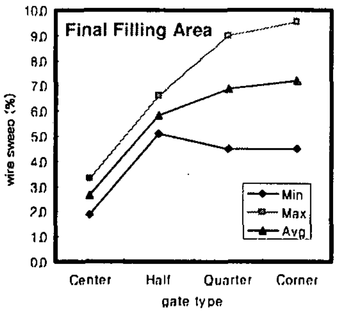
Wire sweeping performance comparison: corner gate & center gate

- **As expected, compared with center gate, wire sweeping of the reduced gate types is more severe near the gate and final filling area of the packages.**
- **Center gate showed less positional dependencies and low wire sweeping values**









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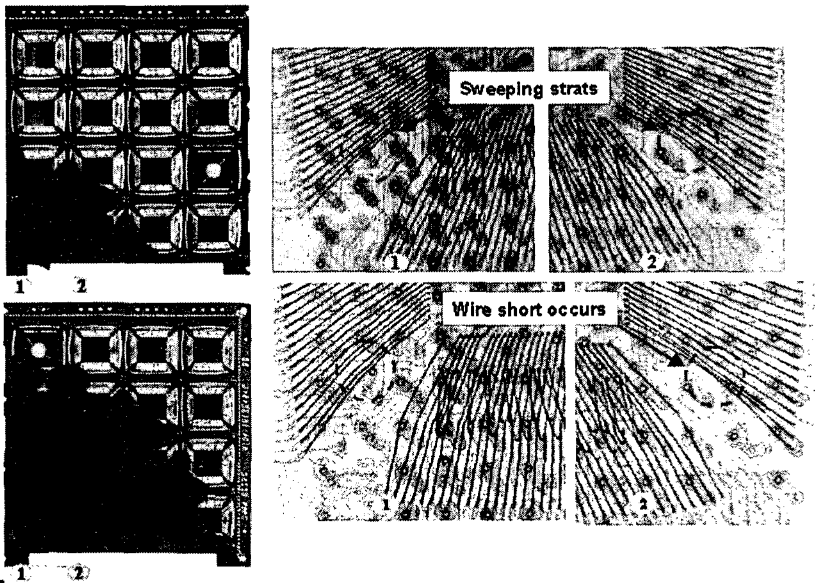
Experiment: Wire Sweeping

Wire sweeping X-ray monitoring results of corner gate type
: Near gate and final filling area



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Experiment: Wire Sweeping

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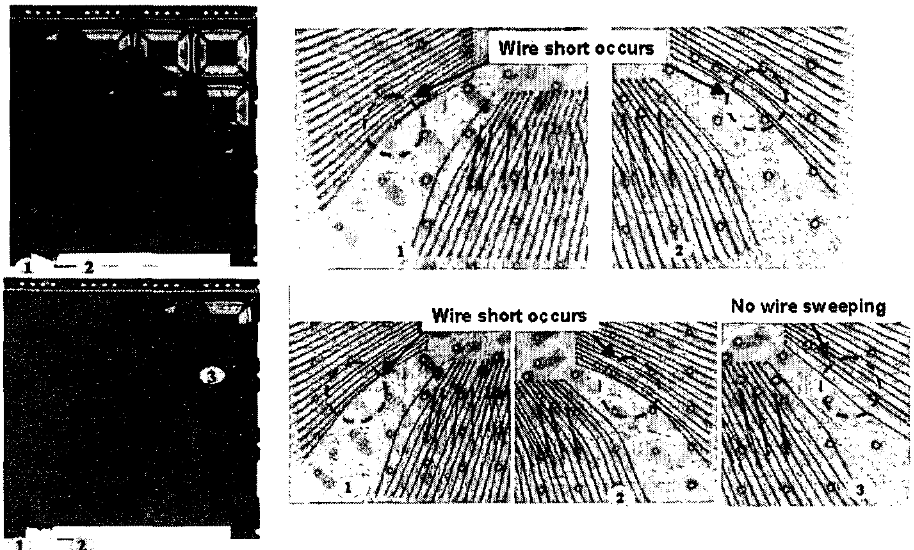

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Wire sweeping X-ray monitoring results of corner gate type
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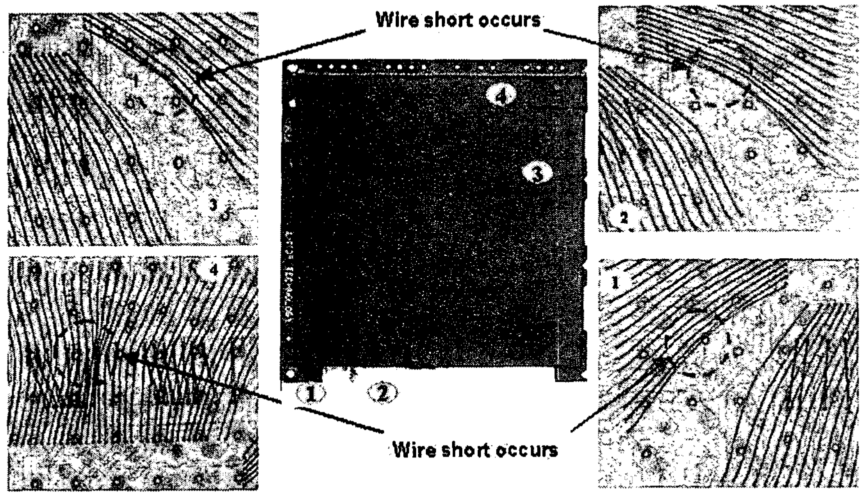

Summary

Mold-Flow in 3 Die Stack CSP of Mold array packaging with different Gate types

- As high density package option such as 3 or 4 die stacking technologies are developed, the major concerning points of mold related qualities such as incomplete mold, exposed wires and wire sweeping issues are increased because of its narrow space between die top and mold surface and higher wiring density.
- Full 3D rheokinetic simulation of Mold flow for 3 die stacking structure case was done with the rheological parameters acquired from Slit-Die rheometer and DSC of commercial EMC . The center gate showed severe void but corner gate showed relatively better void performance.
- But in case of wire sweeping related, the center gate type showed less wire sweeping than corner gate types. From the simulation results, corner gate types showed increased velocity, shear stress and mold pressure near the gate and final filling zone.
- The Experimental Case study and the Mold flow simulation showed good agreement on the mold void and wire sweeping related prediction.
- Full 3D simulation methodologies with proper rheokinetic material characterization by thermal and rheological instruments enable the prediction of micro-scale mold filling behavior in the multi die stacking and other complicated packaging structures for the future application.