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粉末(金屬/陶瓷)注塑成型(PIM)之CAE模流分析技术之应用

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www.moldex3D.com

PIM 產業技術概論

粉末(金屬/陶瓷)注塑成型(PIM)

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- Origin
  - As PIM technology is originated in 1973, the U.S. Space Agency, NASA, the injection molding technology used in powder metallurgy

- PIM is an advanced manufacturing technology for use in a diverse range of industries. PIM can produces the net-shape parts of **high volume high precision components** in all areas of life, looking from **cars and watches to 3C products, DIY tools**, and etc.

粉末(金屬/陶瓷)注塑成型(PIM)應用

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> **Mobile phone component**

> **Medical gear component**

粉末(金屬/陶瓷)注塑成型(PIM)應用

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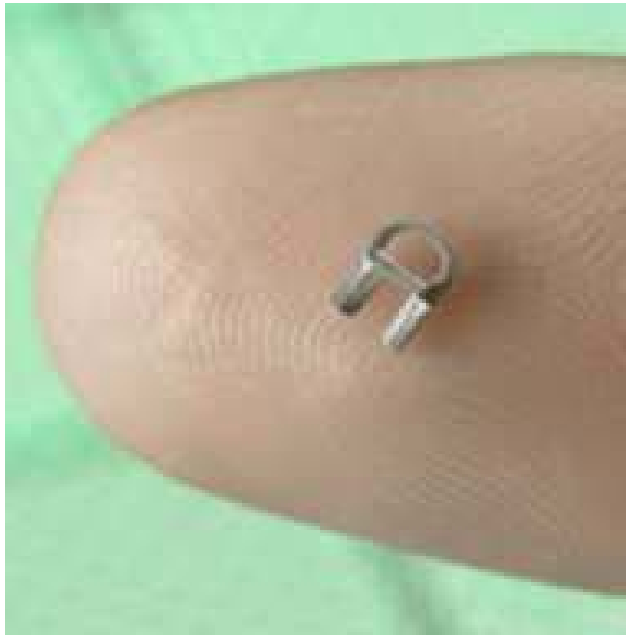
> **Medical pin component**



> **Trigger guard for hunting rifle**

粉末(金屬/陶瓷)注塑成型(PIM)之基本程序

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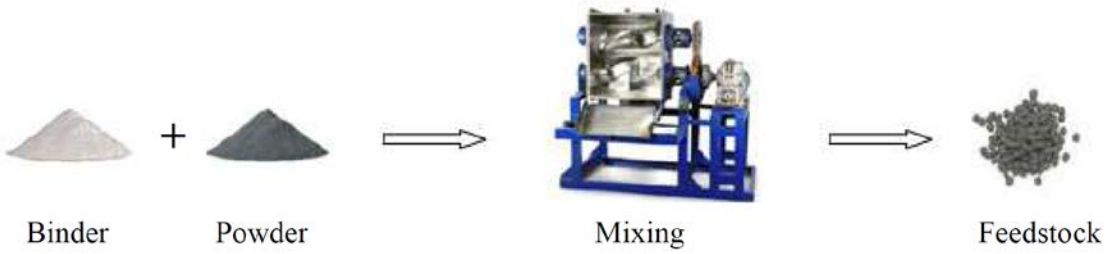
> Mixing
  - Preparing of a mixture of powder and a binder



> Injection molding
  - Moulding of green part by injection of the powder-binder mixture into the mould

粉末(金屬/陶瓷)注塑成型(PIM)之基本程序

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- Debinding (脫酯)
  - Removal of binder

- Sintering (燒結)
  - Powder particles sinter into a dense structure

De-binding Stage (脱酯程序)

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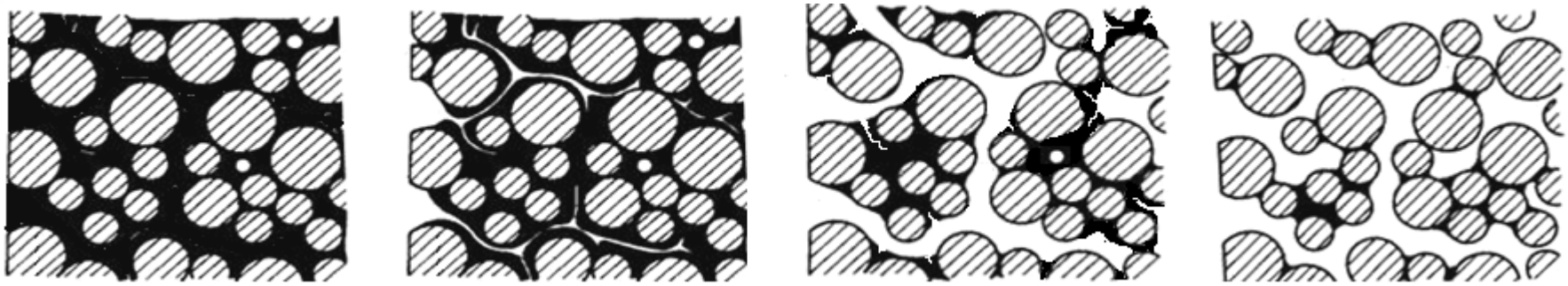
the binder is removed from the molded part

Green part (生胚) → Brown part



Initial Middle Final

Sintering Process (燒結)

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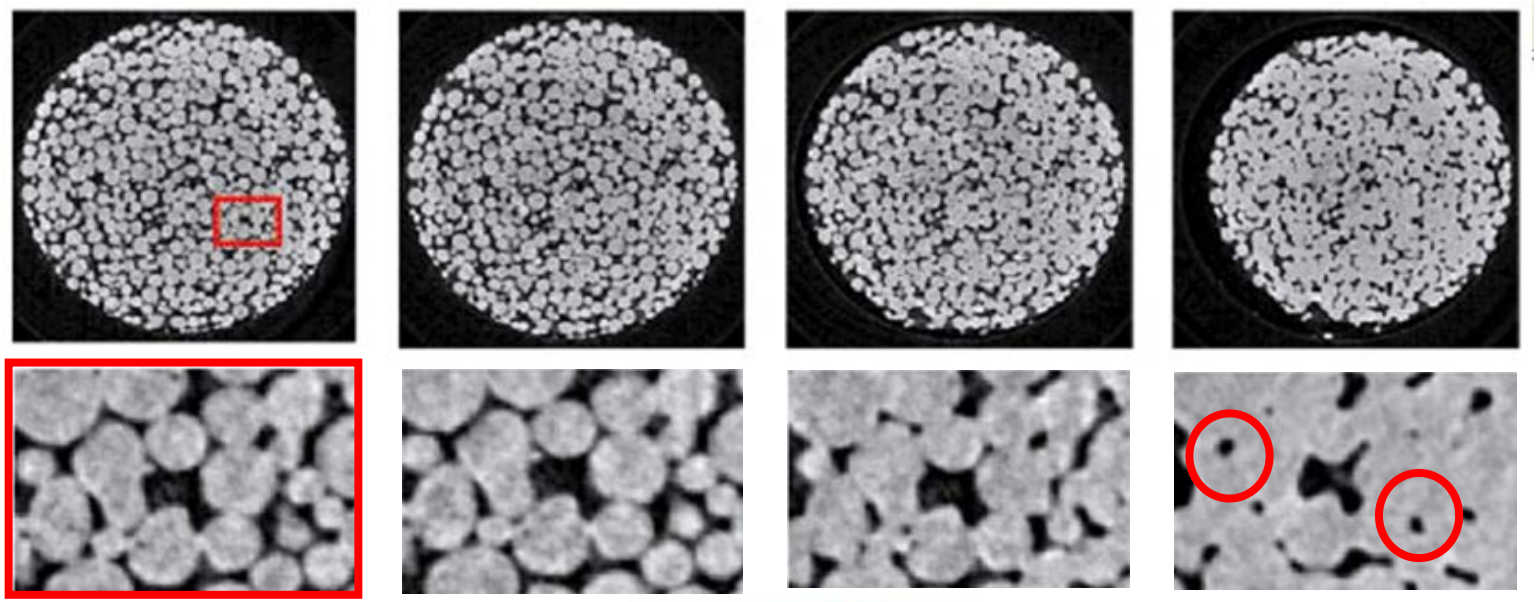
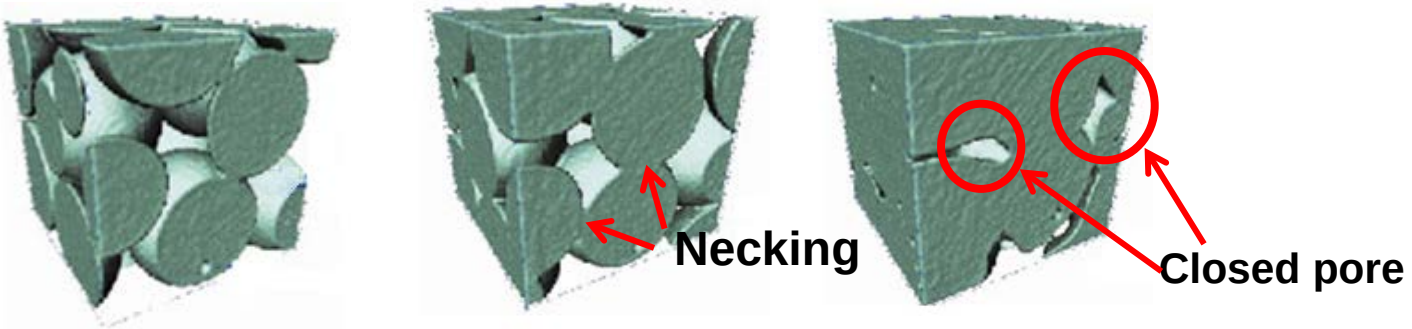
Brown part

Sintered part





Initial stage

Middle stage

Final stage

PIM 產業問題與挑戰

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- 品質與量產如何確保?
  - 外觀問題:
    - 黑線
    - 尺寸精度 (收縮)
  - 內在問題
    - 粉末分佈問題
    - 收縮不均問題
    - 材料成本問題

PIM 產業問題與挑戰
了解製程

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- PIM製程
  - 從 1st stage: Green part → 2nd stage: 脫酯Brown part → 3rd stage: sintering
  - (Feedstock: Metal Powder+binder) → (Metal + 少量 binder) → (幾乎Meta都是 Metal)

- 從品質與量產觀點探索
  - 黑線: 主要來自1st stage: Green part?
  - 尺寸精度 (收縮):
    - 1st stage: Green part 貢獻多大?
    - 過去賴以為主線收縮: 1st stage: Green part 三維收縮?

設定目標

- 如何協助解決品質與量產問題
  - 主要鎖定 1st stage: Green part 成型機理與影響
    - 黑線成因: 1st stage: Green part 之影響
  - 尺寸精度 (收縮):
    - 1st stage: Green part 貢獻多大?
    - 1st stage: Green part 三維收縮?

為何須要應用 CAE 克服問題與挑戰

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- 品質與量產
  - 取決於四大因素之整合: 無法快速猜到
    - 產品設計
    - 模具設計
    - 材料及其特性
    - 機台與其操作條件

- 經驗累積傳承與新世代產品開發

PIM 製程面臨嚴峻的挑戰
整合構成非常複雜之系統

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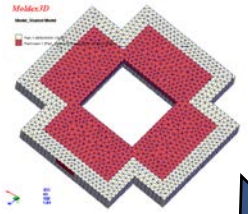
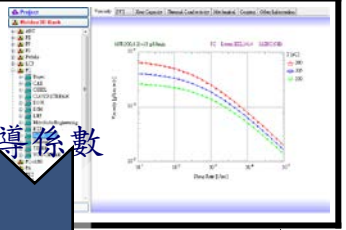
網格

- 塑件與嵌件
- 流道配置
- 模座與水路
- ：



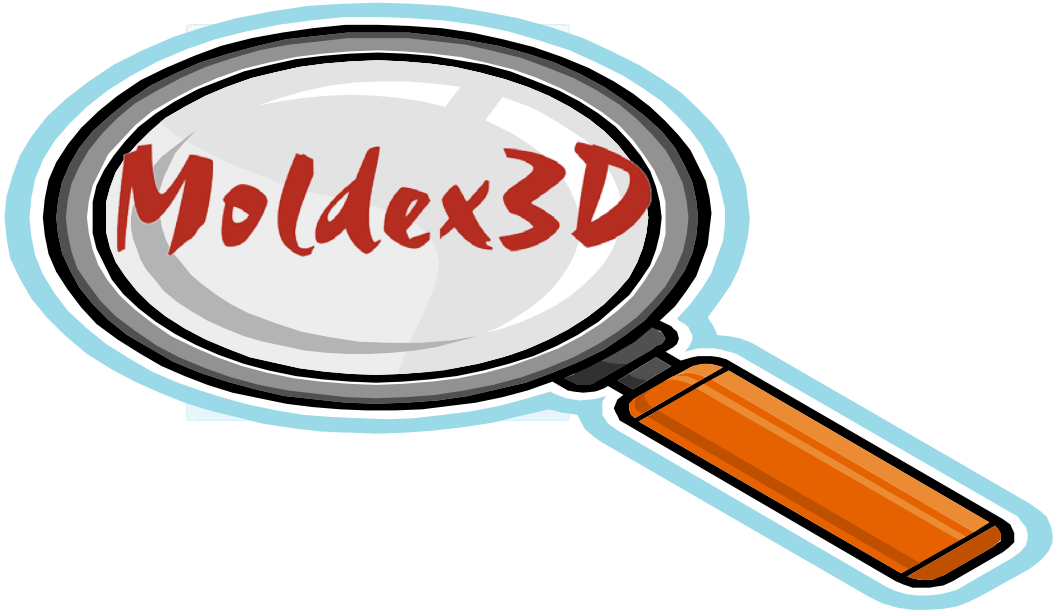
材料

- PVT
- 黏度
- 比熱與熱傳導係數
- ：



成型條件

- 射出時間
- 融膠溫度
- 模具溫度
- ：

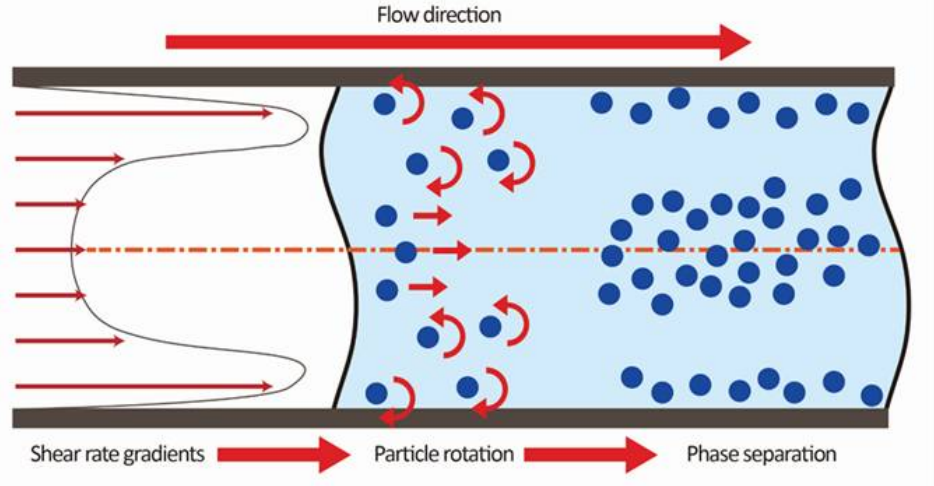


理論與文獻回顧
Black-Line Defect

Key Issue: Black-Line Defect

- Listen to industry, people often talk about “Black Lines” as an indicator for **phase separation** between binder and powder. This defect causes real quality issues.

- **Phase separation is also called the Shear-induced Particle Migration**
  - Near wall, the maximum shear rate exists, so that the dispersible particles or low powder concentration; in the center area, the minimum shear rate makes high concentration.



Key Issue: Black-Line Defect

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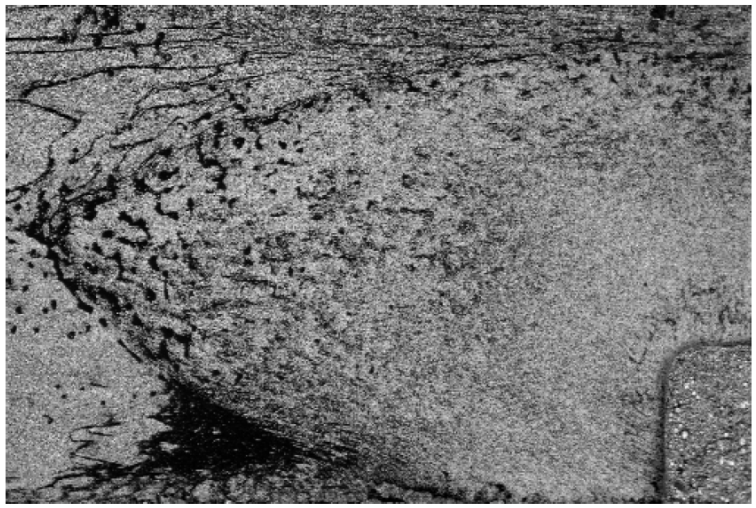
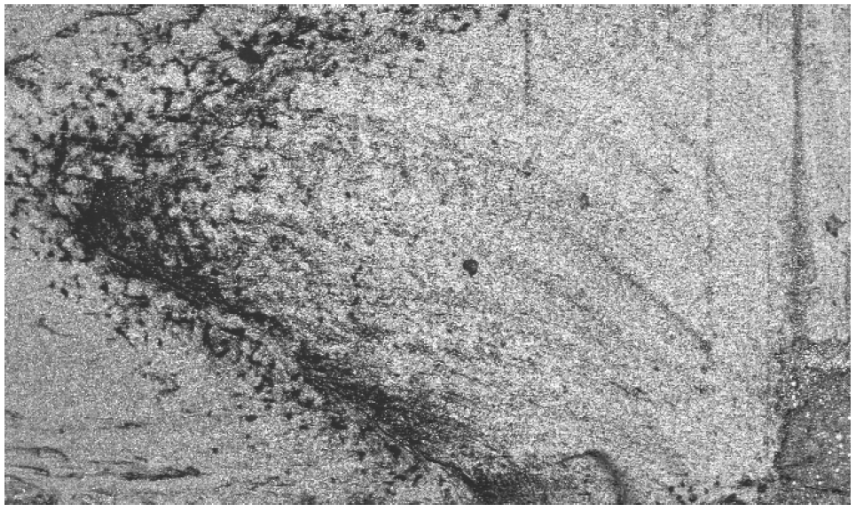
- Phase separation
  - Phase separation is a term commonly used for an adhesion failure of powder and binder during injection molding step in PIM.
  - A basic requirement for a high quality production is a homogenous mixing of powder and binder, adhesion and mutual interaction between them
  - A separation of these two ingredients is causing quality issues such as visual defects, mechanical weak points, warpage and local hollowness.
  - Phase separation is a defect that can be easily recognized in some feedstocks.

Black-Line Defect

> *Various phase separation on the surface of molded part*

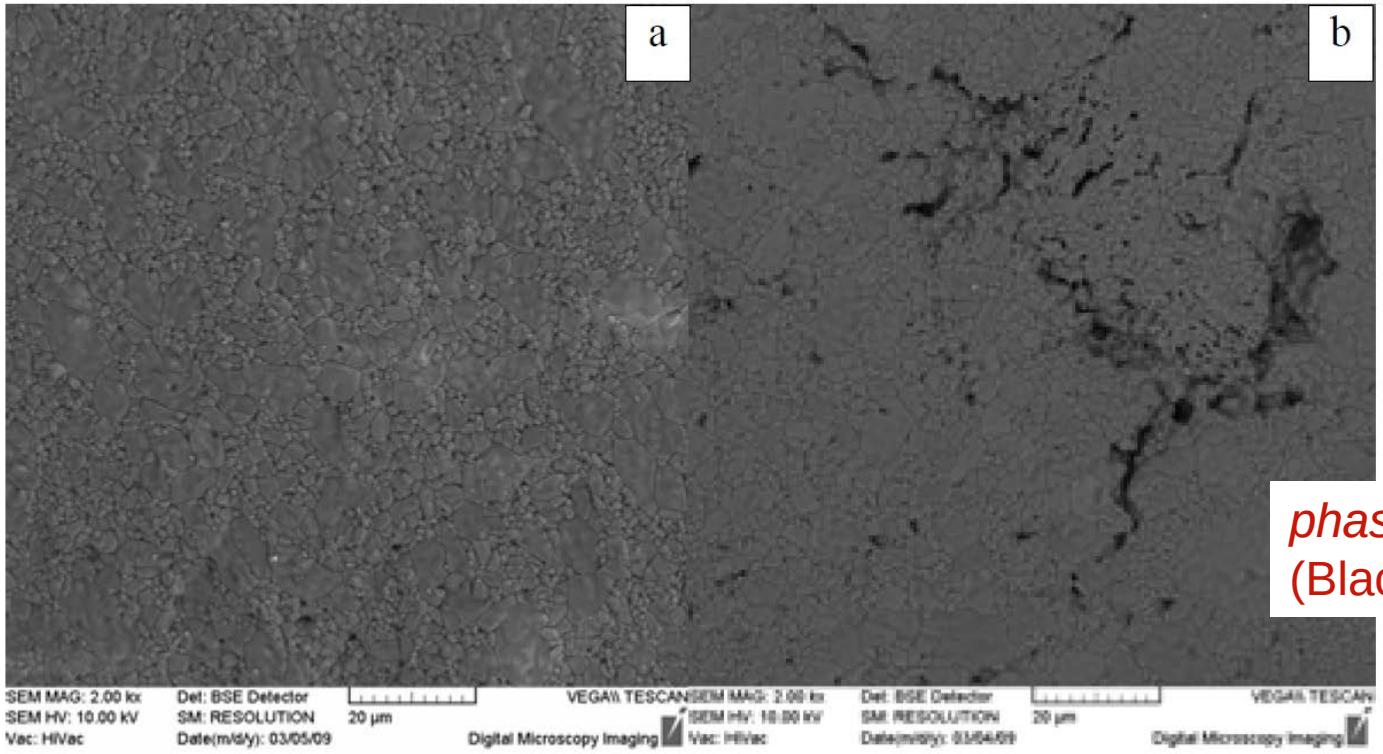




SEM micrographs

Homogenous surface

Inhomogeneous surface



phase separation
(Black-Line)

Feedstock flow changes the separation pattern

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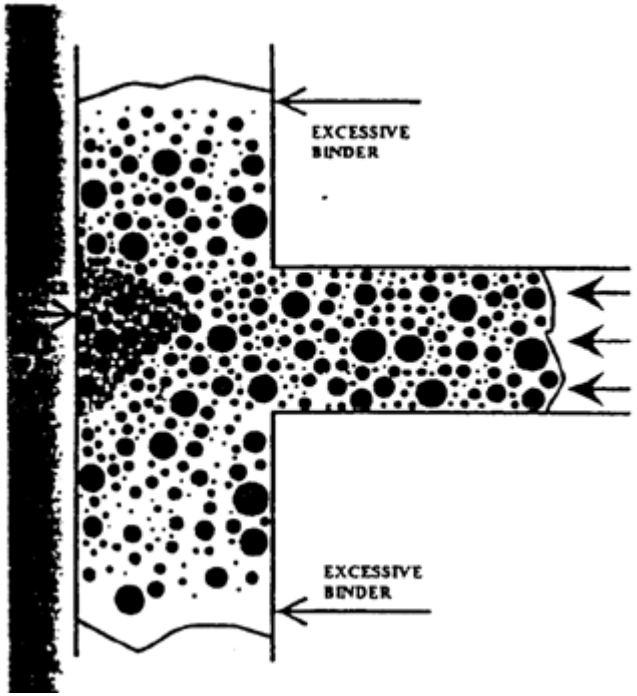
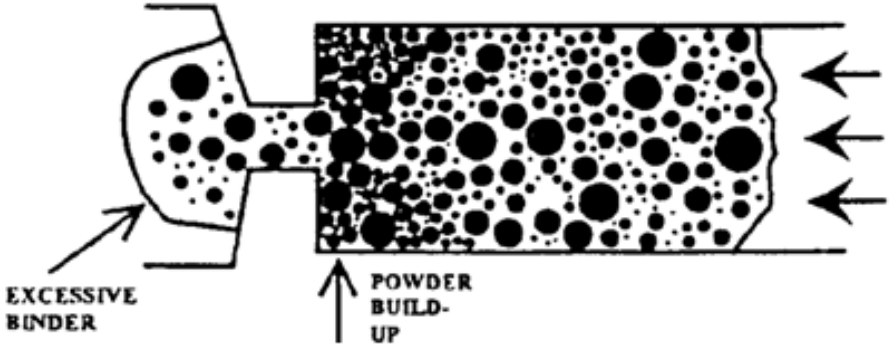
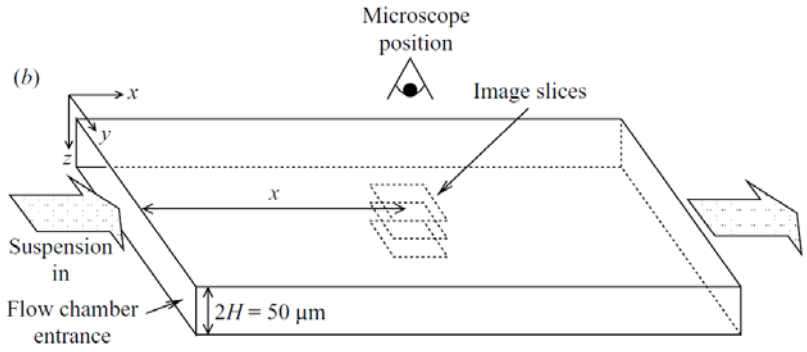
> A: T Shape

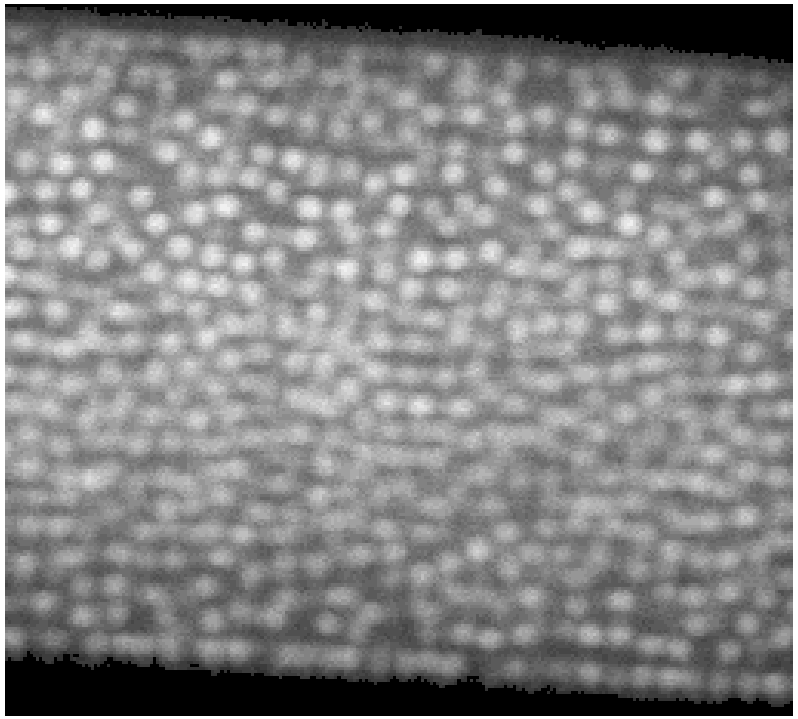


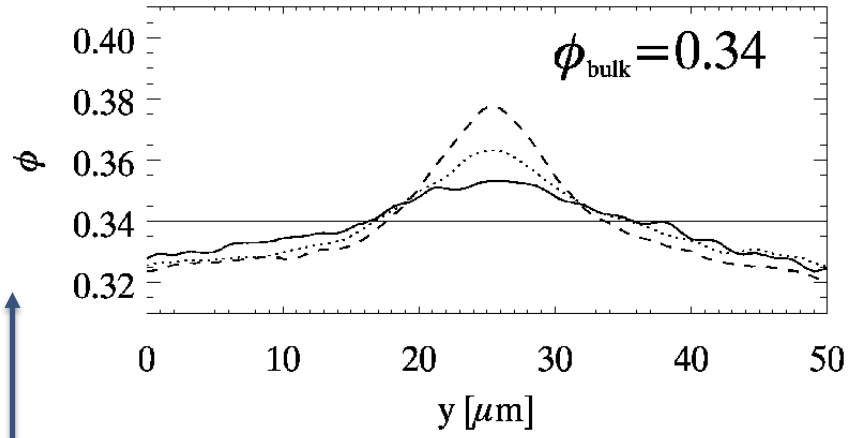
B: Contraction-Expansion



Shear-induced Particle Migration Experimental Observation







The particle size of 1.5 μm, the average volume fraction of 34%

50 μm

http://www.physics.emory.edu/~weeks/lab/flowing.html

成果與實務案例分享與討論

實務案例分享

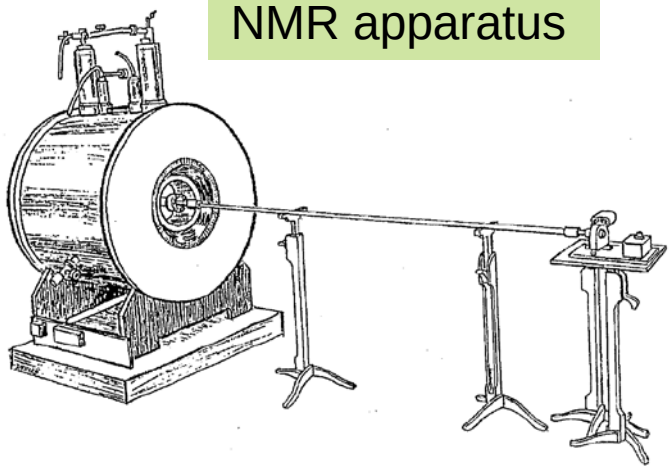
1. 粉末密度分佈預測
2. 粉末與黏劑 相分離預測
3. 齒輪黑線預測
4. 消除表面黑線的測試

Case 1:
粉末密度分佈預測
Accuracy of Powder Concentration

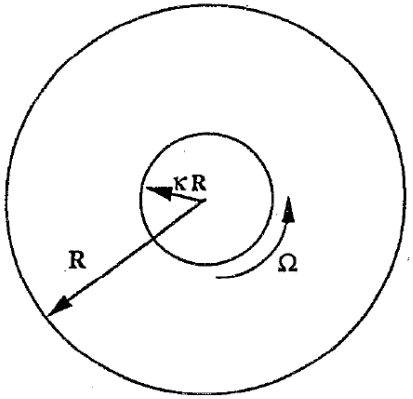
Powder Concentration Measurement

- Experimental NMR imaging apparatus for particular migration studies in Couette flow between concentric, rotating cylinders. The stationary outer-cylinder radius is R (2.38 mm) and the rotating inner-cylinder radius is kR (0.64 mm) with angular velocity Ω, where k<1. The length of cylinder is 25 mm.
- **The Fluid of interesting is that 675 μm PMMA spheres immersed in Newtonian Oil with volume fractions of 45, 50, and 55.**

NMR apparatus



Couette flow



Result of Powder Concentration Distribution

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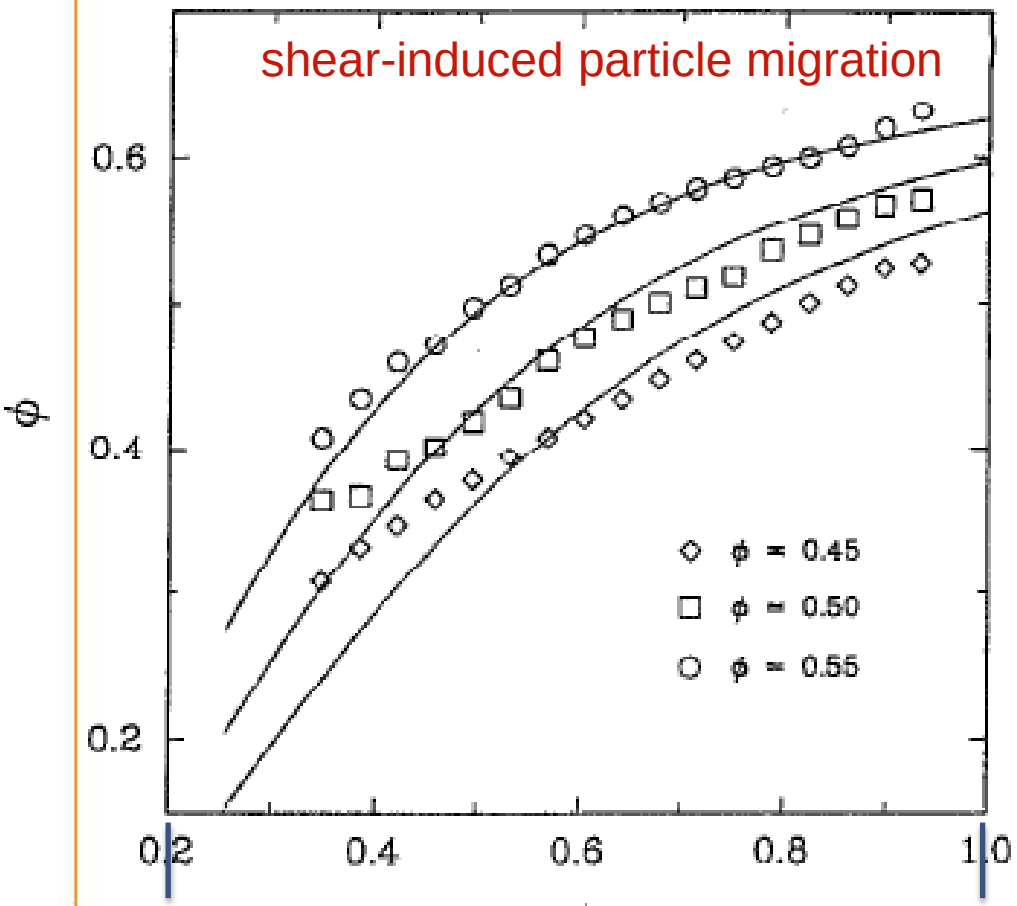
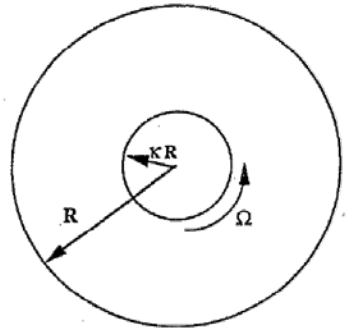
– **Near stationary outer-cylinder , the high concentration is due to maximum shear rate, but close to rotating inner-cylinder , the low concentration for minimum shear rate**



Line: **Diffusive Flux Model Prediction**
Symbol: Experimental values of Philips et. al.



catch the experimental data points, as PIM quantitative comparison

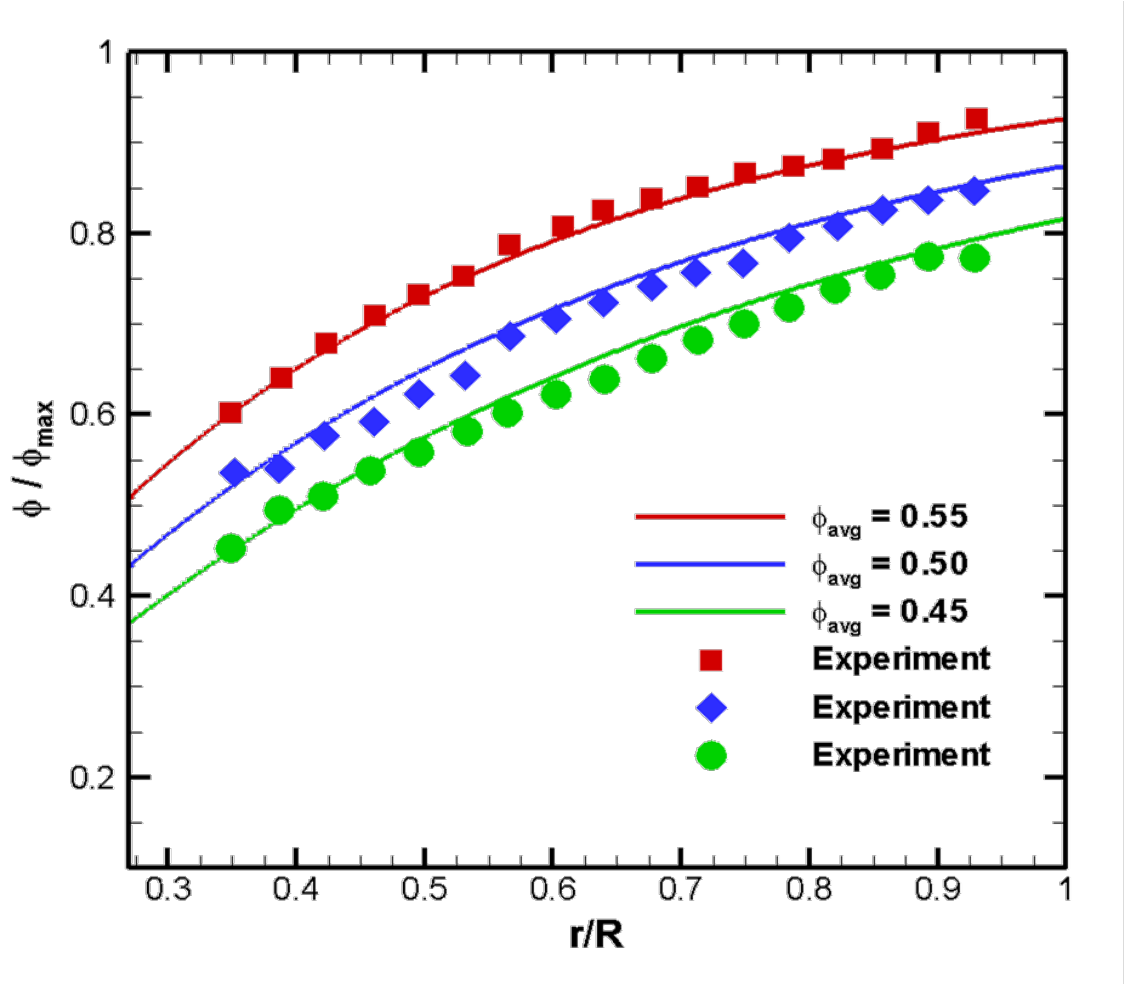
Ref.: Physics of Fluids A: Fluid Dynamics, Volume 4, Issue 1, 1992, pp.30-40

rotating inner-cylinder radius

stationary outer-cylinder radius

Moldex3D Prediction

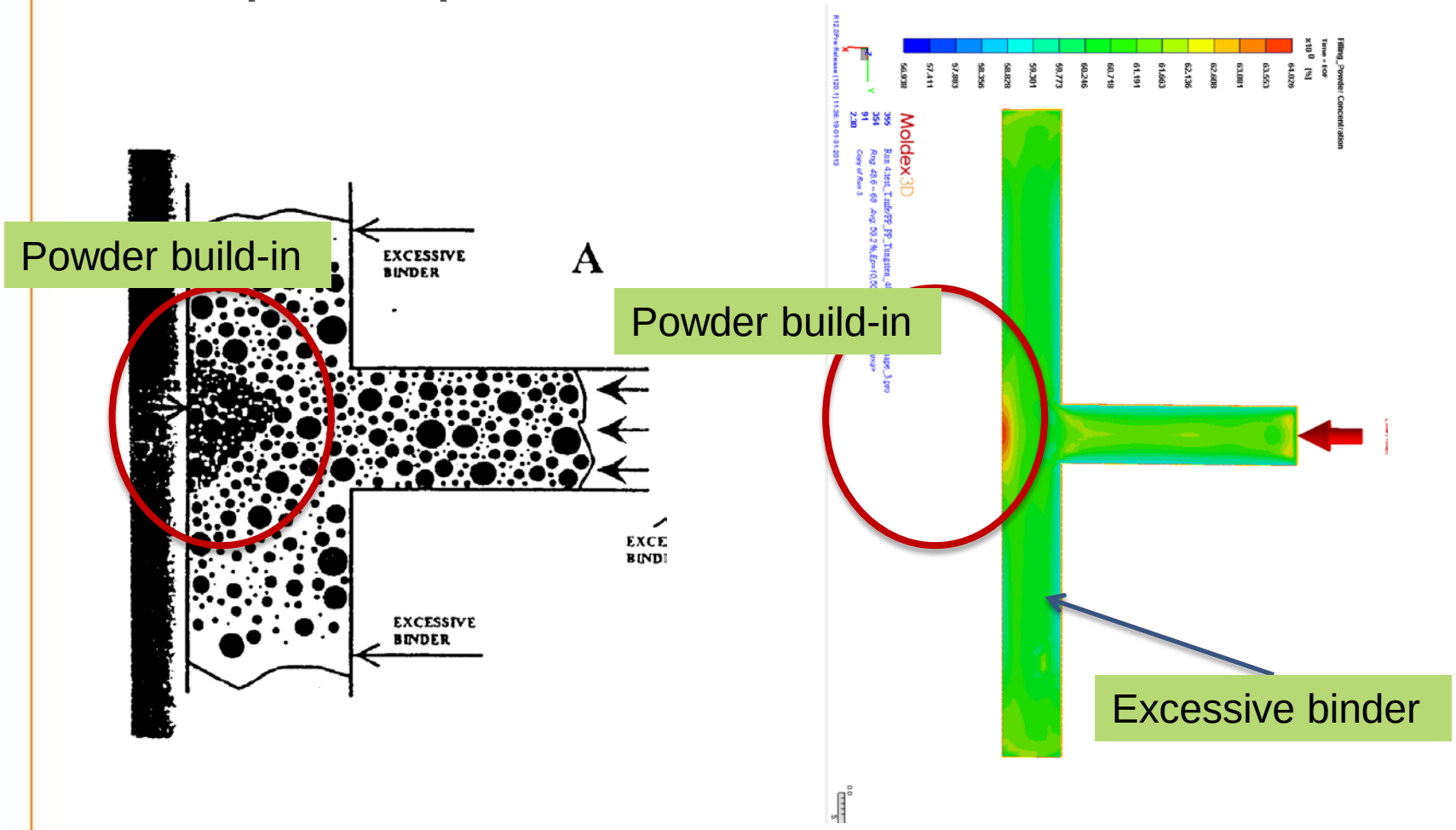
> The excellent predictions are very close to experimental points



Case 2:
粉末與黏劑 相分離預測
Moldex3D's Prediction of Phase Separation

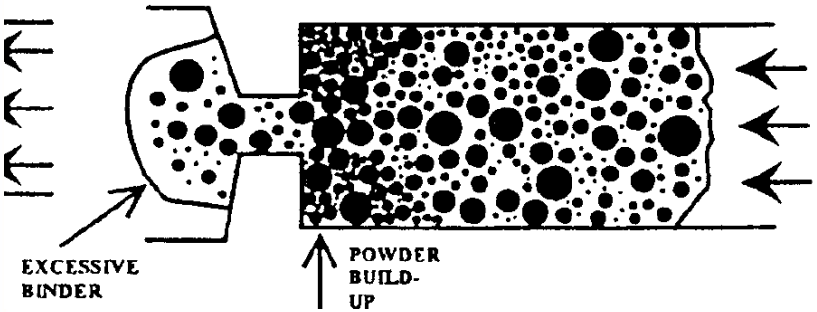
T shape

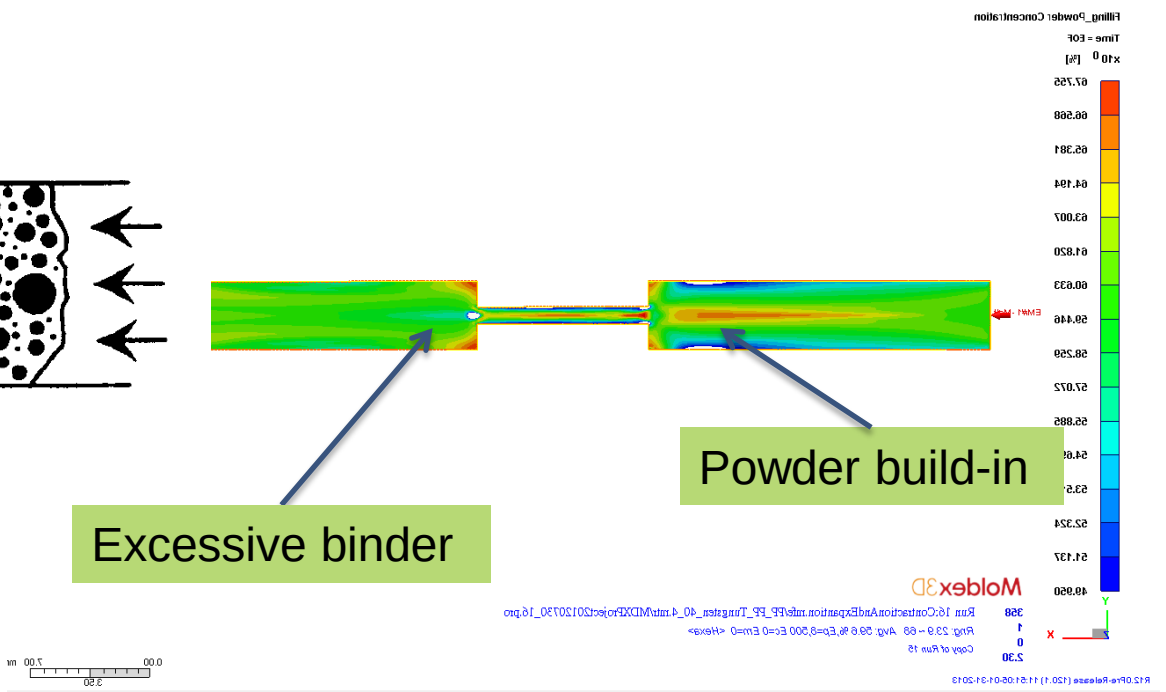
> Separation pattern



Contraction-Expansion

> Separation pattern





Case 3:
齒輪黑線預測

A Standard Gear

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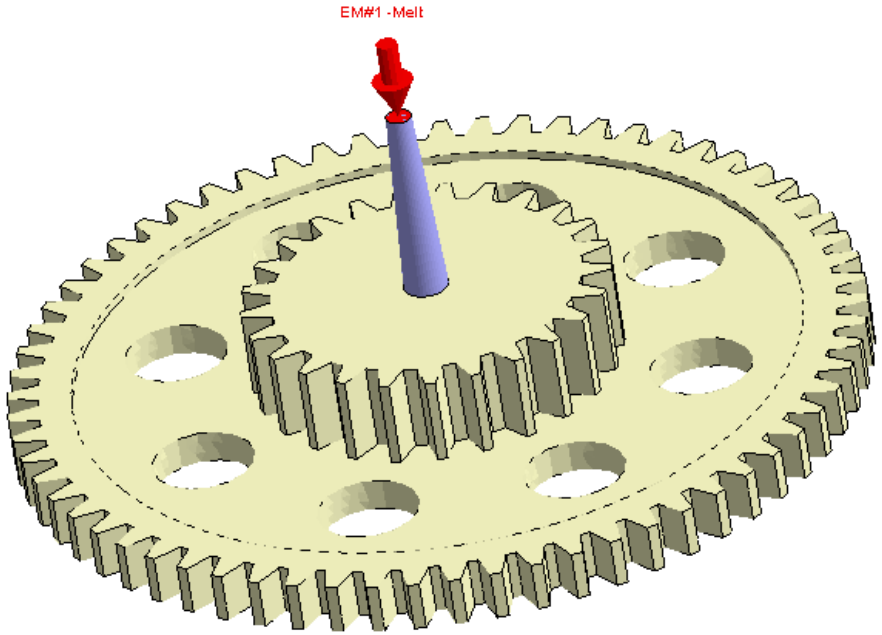
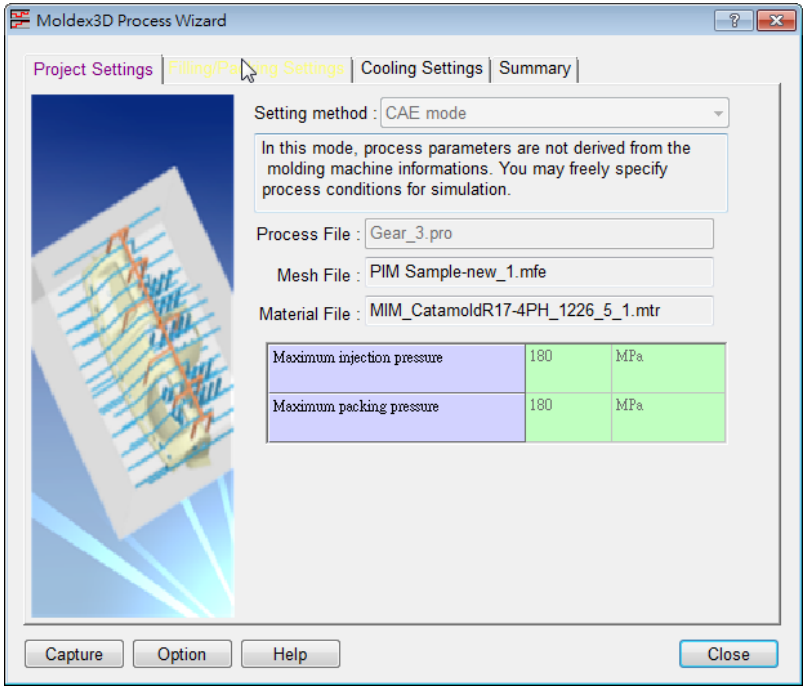
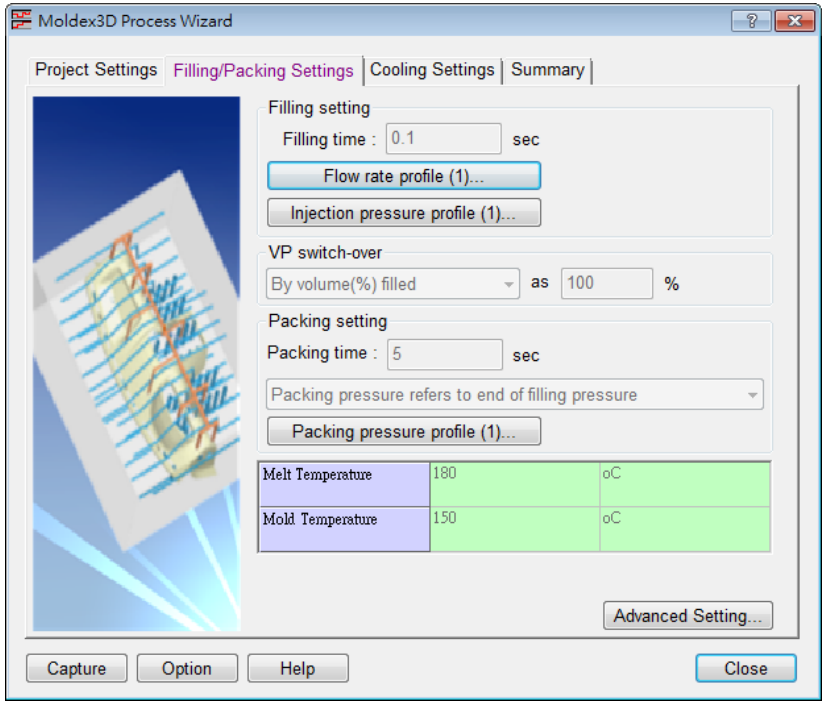
> Input Mesh



Operating Condition

- Injection Temperature: 180 °C
- Mold Temperature: 150 °C
- Filling Time = 0.1 sec





Material Properties

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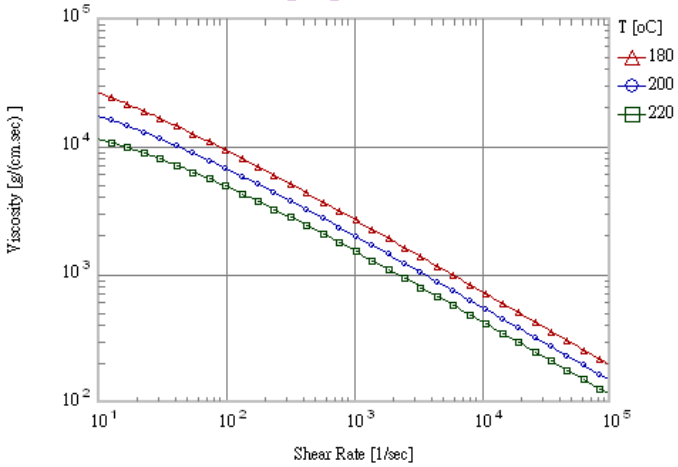
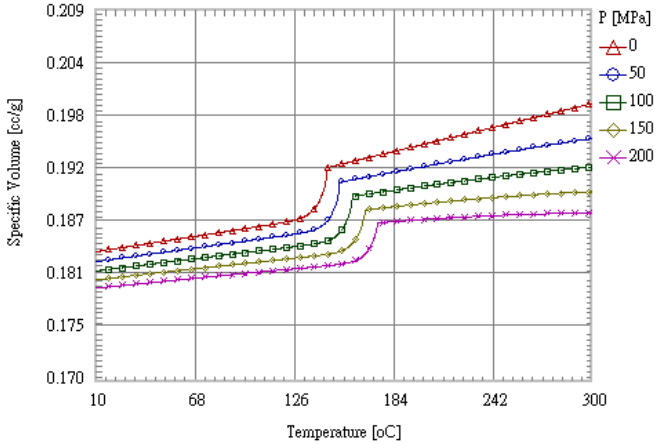
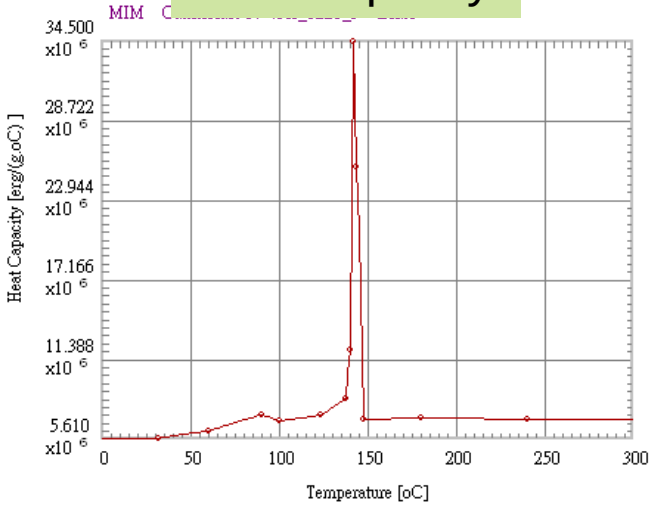
Viscosity



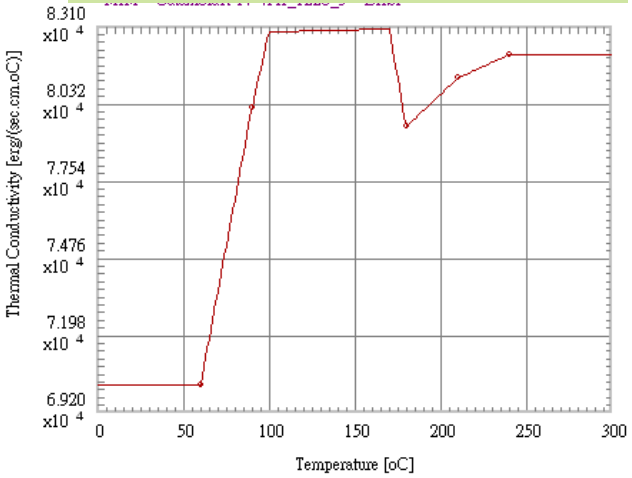
PVT



Heat capacity



Thermal conductivity



Power Information

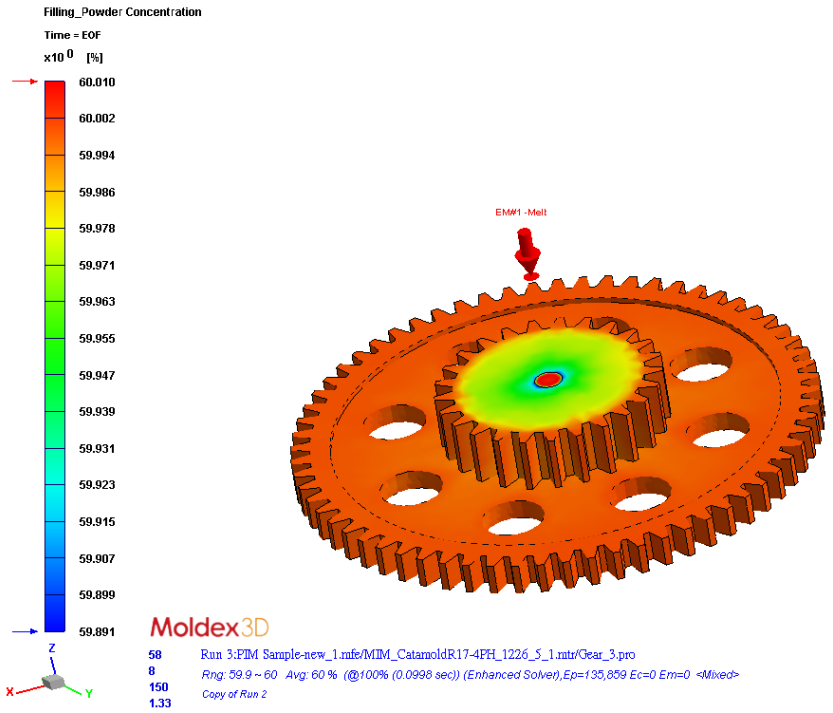
> Input powder size, bulk powder concentration, and power friction index (model parameter)

Polymer | Grade Name | Producer	MIM | CatamoldR 17-4PH_1226_5 | BASF
Powder information	Powder-filled polymer
Powder specific	Alloy
Powder size	0.001 (mm)
Bulk powder concentration	60 (vol%)
Maximum powder concentration	68 (vol%)
Powder friction index	5 (-)

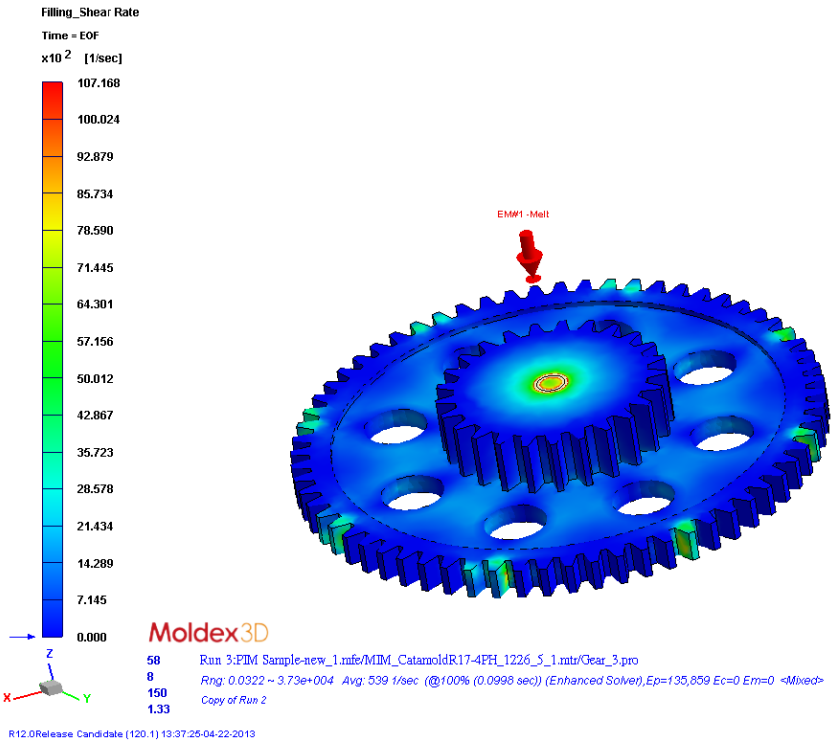
Filling Stage

> Concentration vs Shear rate

Powder Concentration



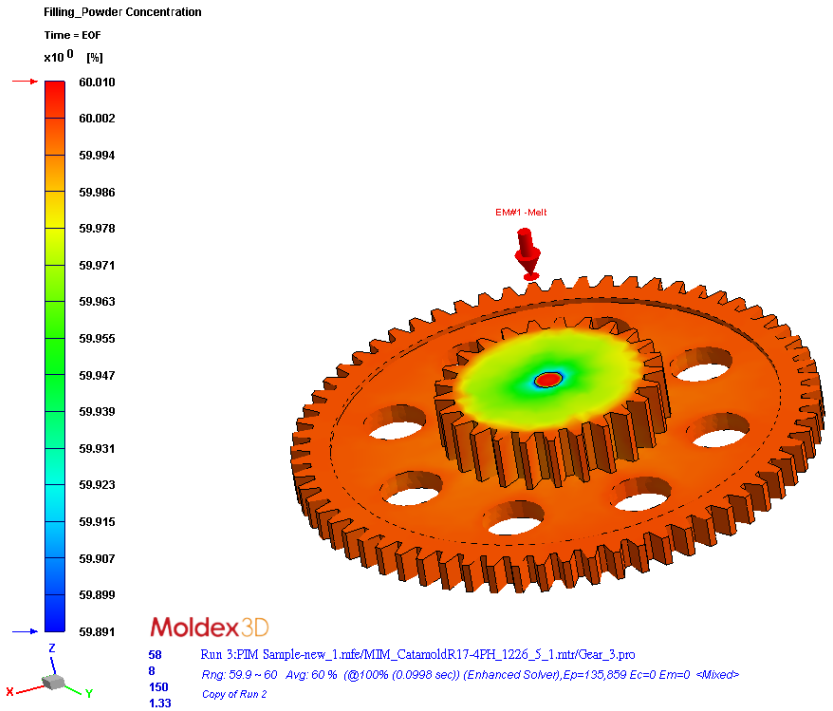
Shear Rate



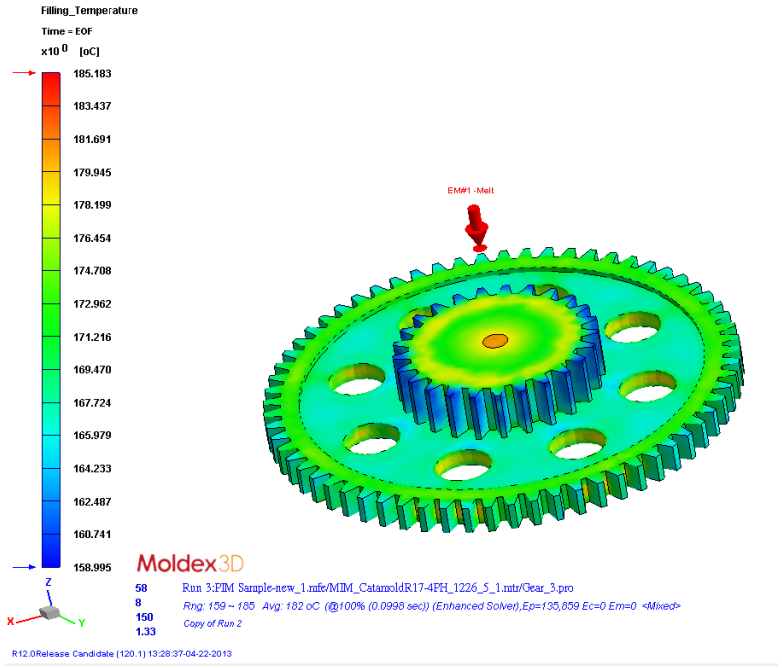
Filling Stage

> Concentration vs Temperature

Powder Concentration



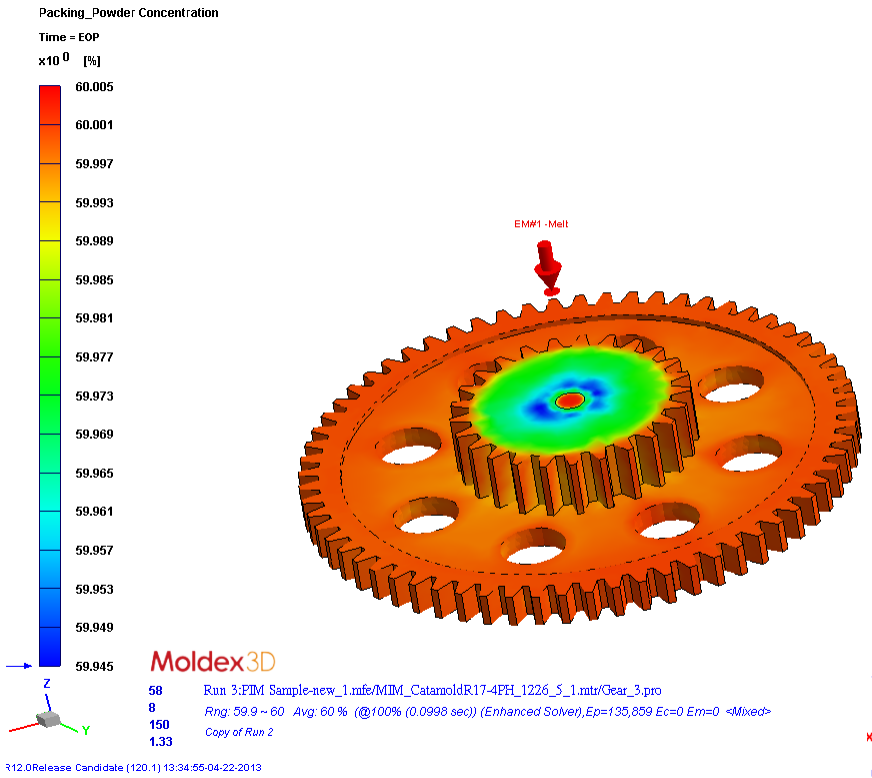
Temperature



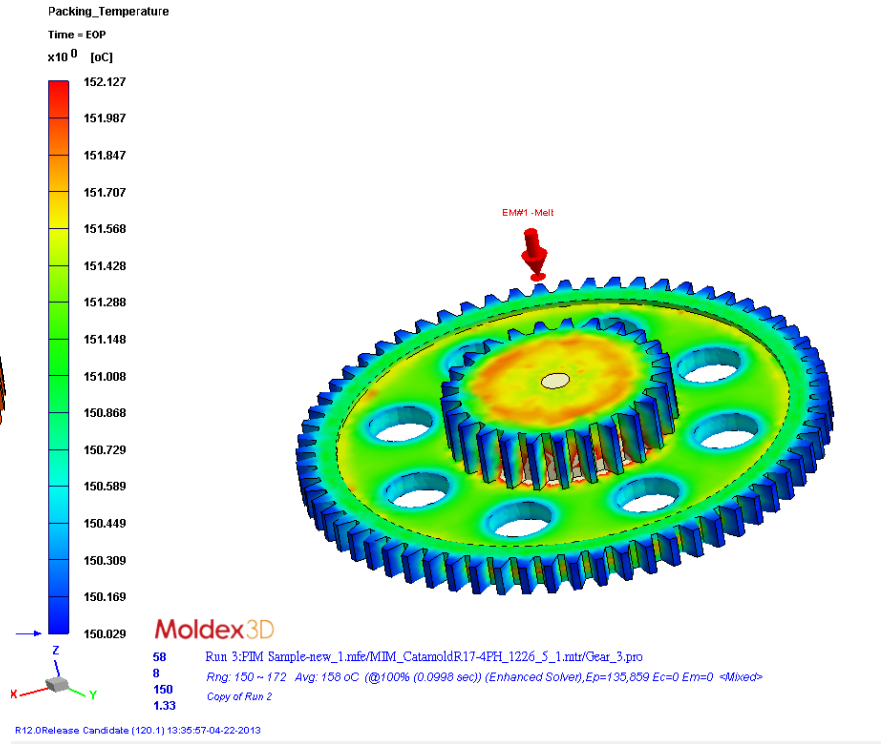
Packing Stage

> Concentration vs Temperature

Powder Concentration

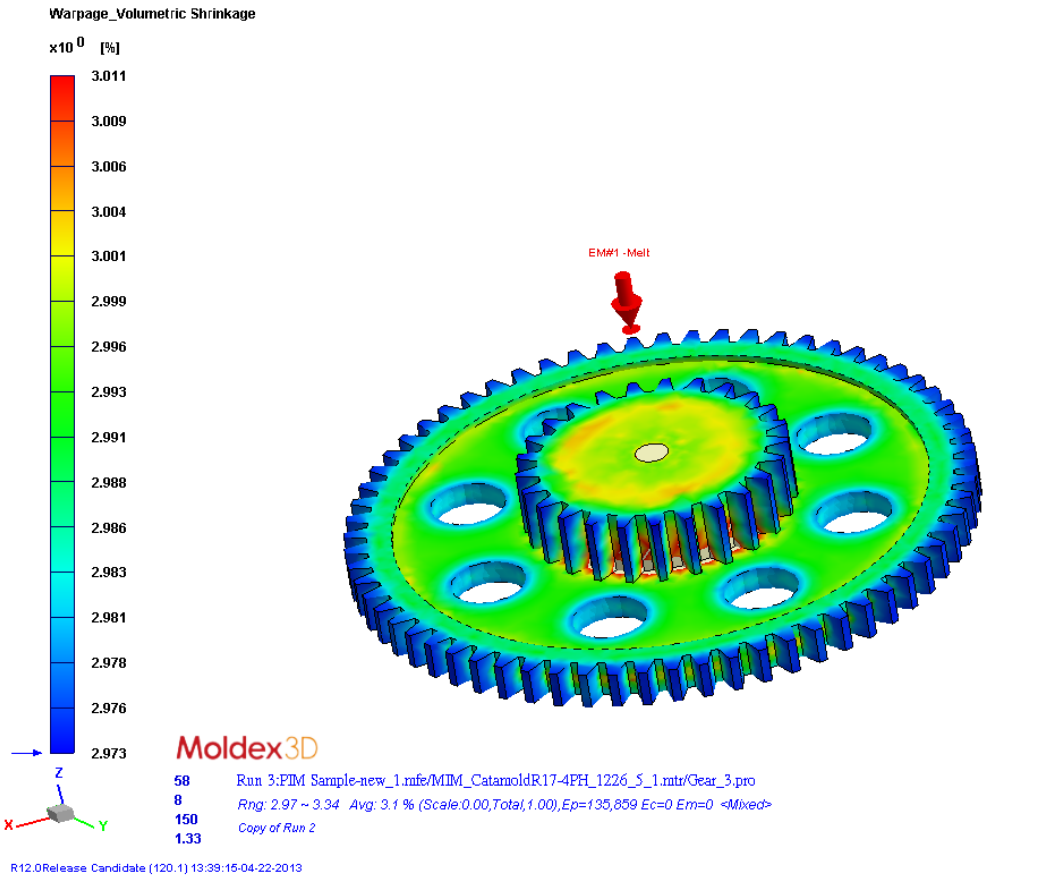


Temperature



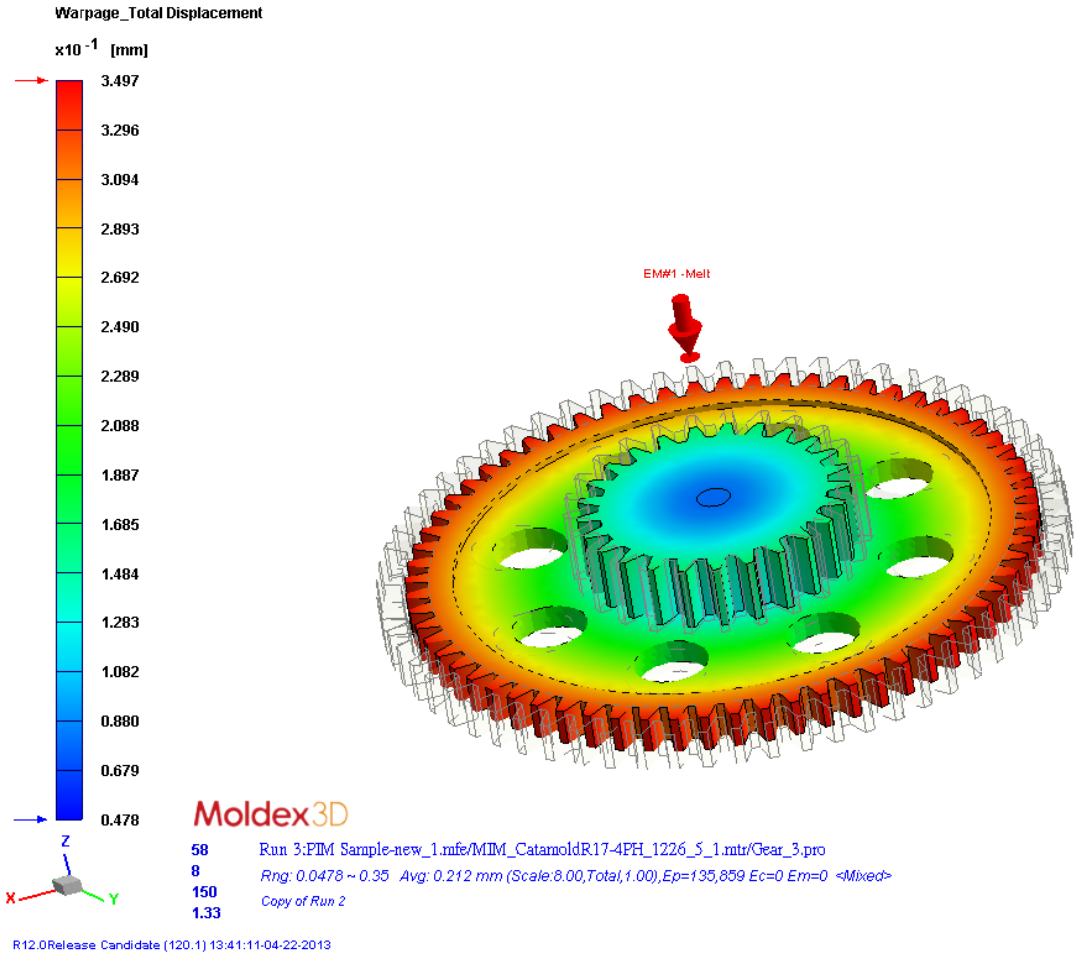
Warpage

> Volumetric Shrinkage



Warpage

> Total Displacement



齒輪的粉膠分離結果

Moldex3D

> 分膠分離出現在齒輪的尖端 (tip)

粉膠分離結果
(黑線)

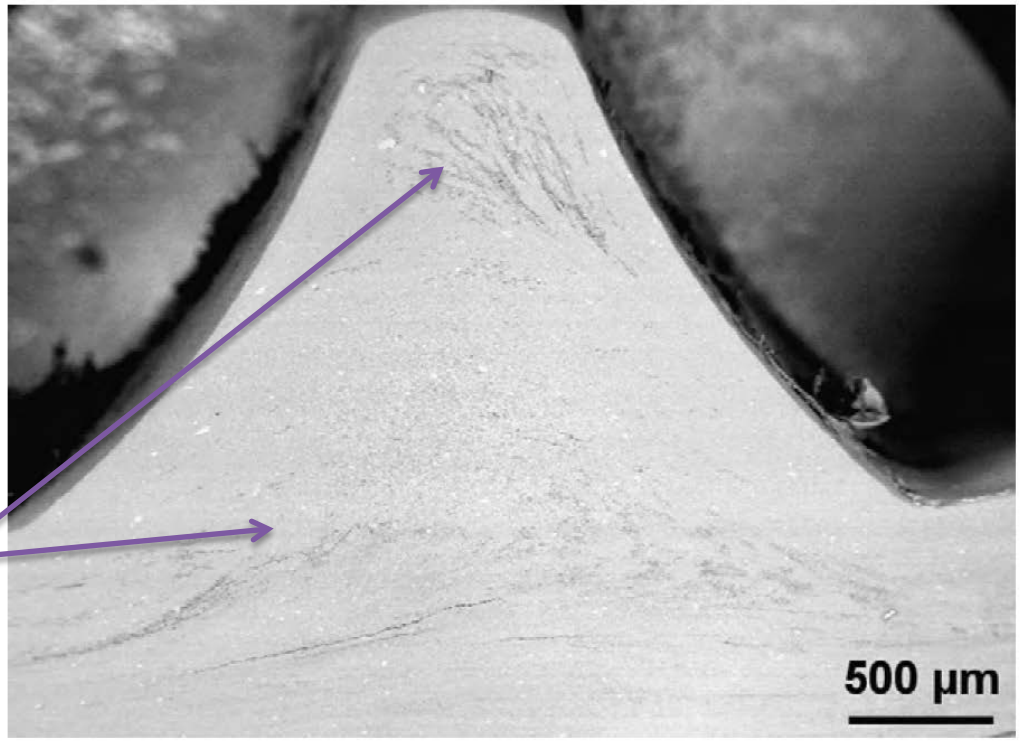
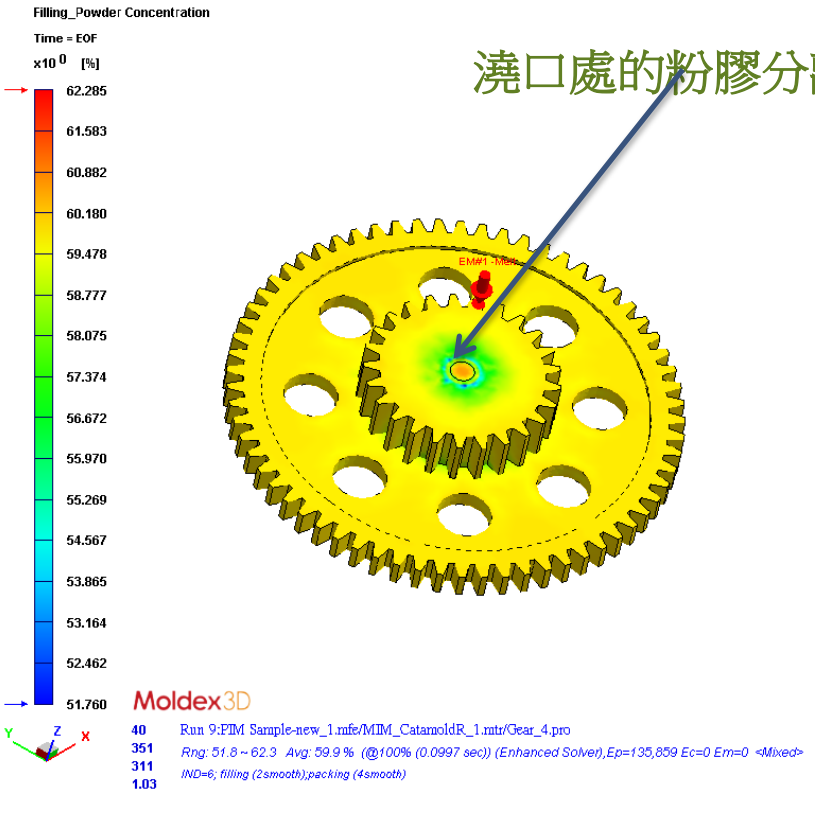


Fig. 3. Binder segregations in a gear tooth of GW1.

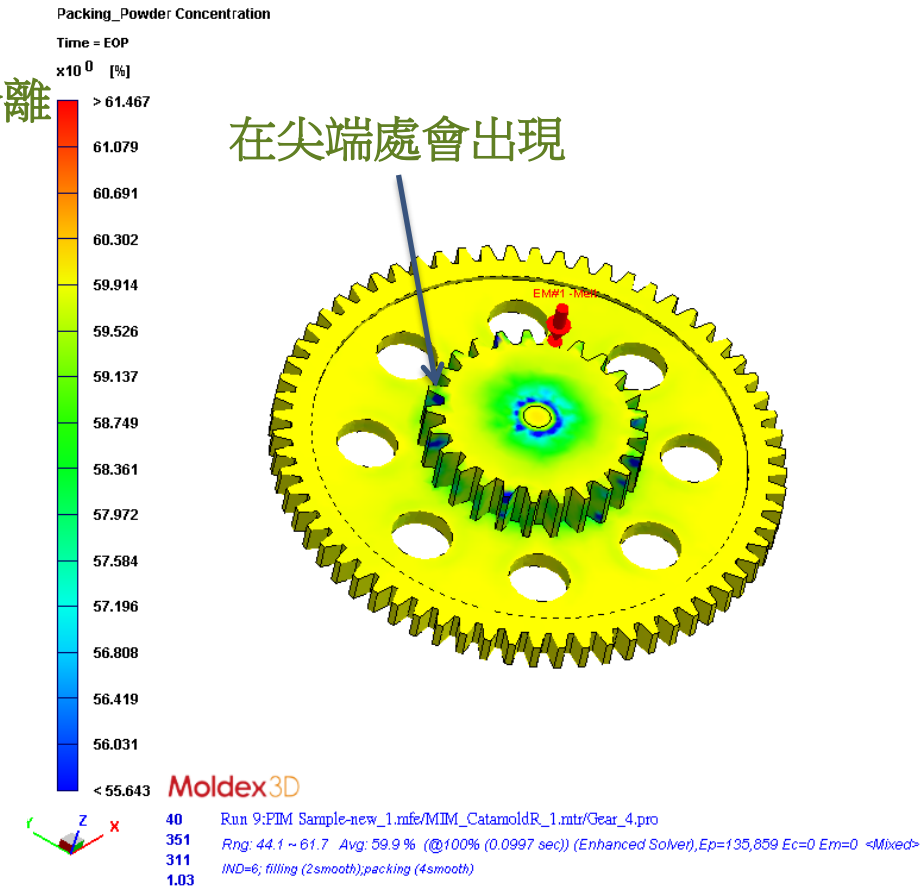
MDX-PIM Gear

> Index = 6; filling-smooth = 2 for and packing-smooth = 4

Filling



Packing



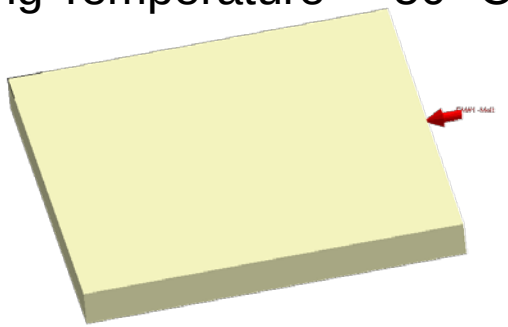
Case 4
消除表面黑線的測試

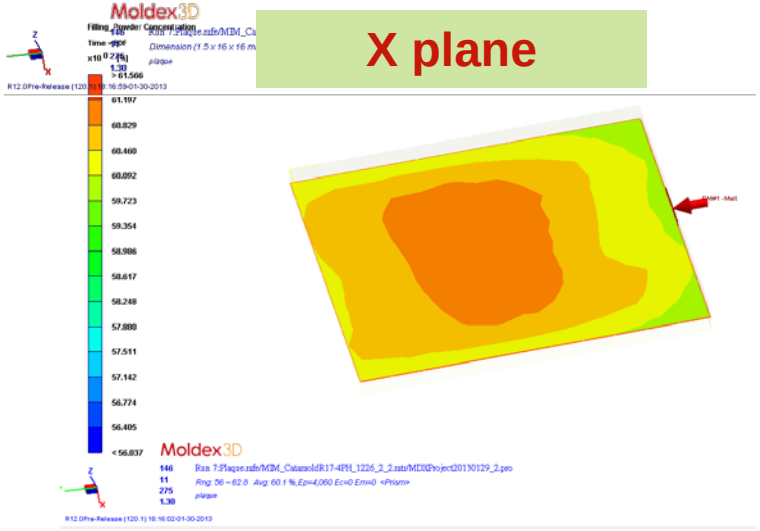
Plaque

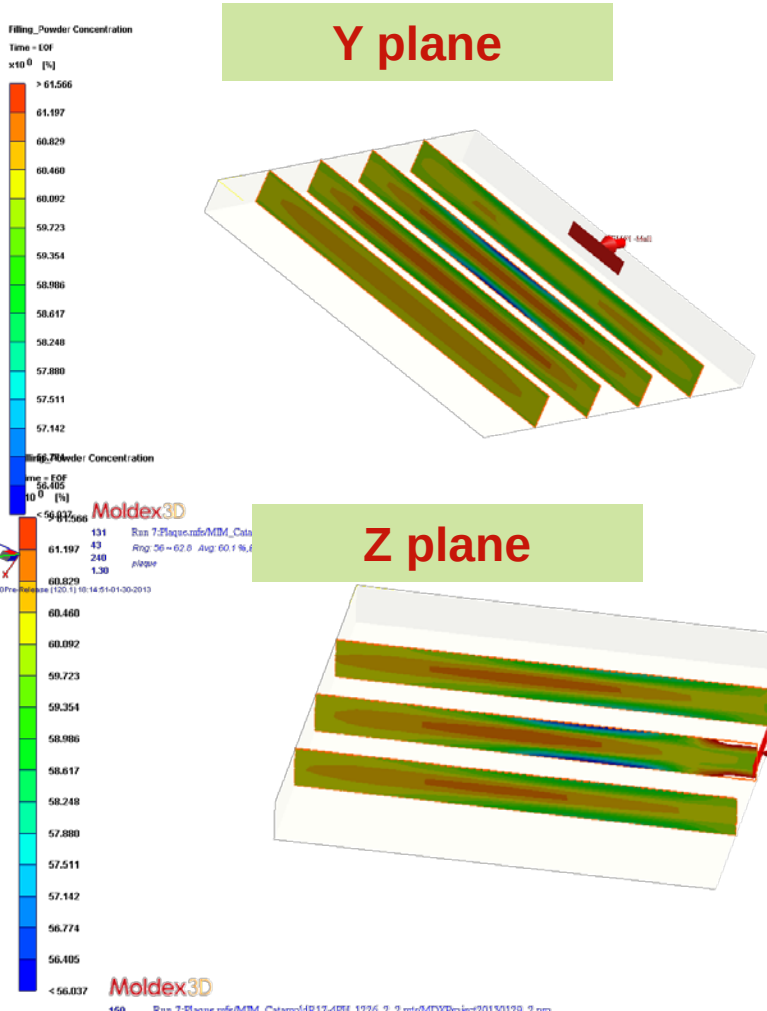
> 頗開XYZ三個面的Powder concentration分佈, 濃度大小都呈現中間區域高過邊界區域

Filling time: 0.1 sec

Molding Temperature = 50 °C







表面濃度特徵

Moldex3D

> 在入口附近會有濃度極高與極低區域產生, **濃度較低的區域是最有可能發生黑線區域**

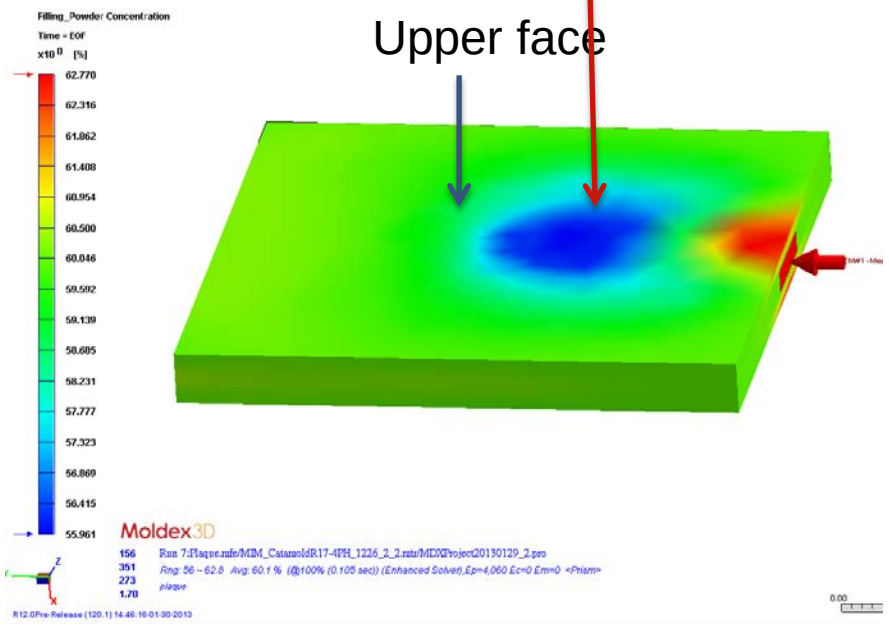
Filling time: 0.1 sec

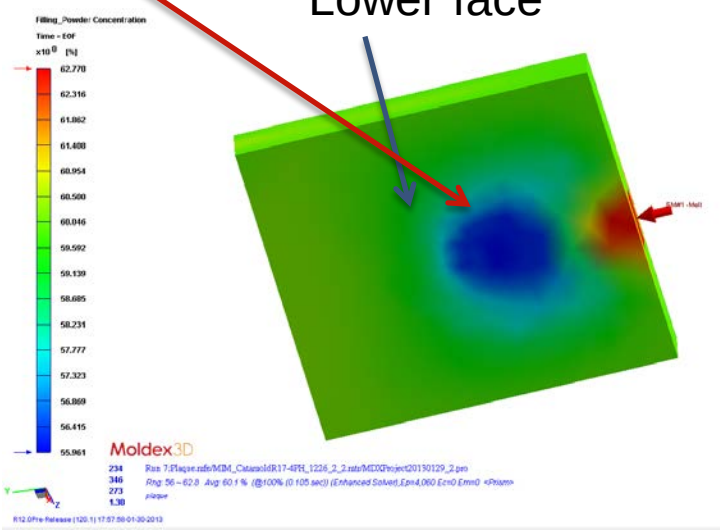
Molding Temperature = 50 °C

濃度範圍 (%): 55.961-62.771

Upper face

Lower face



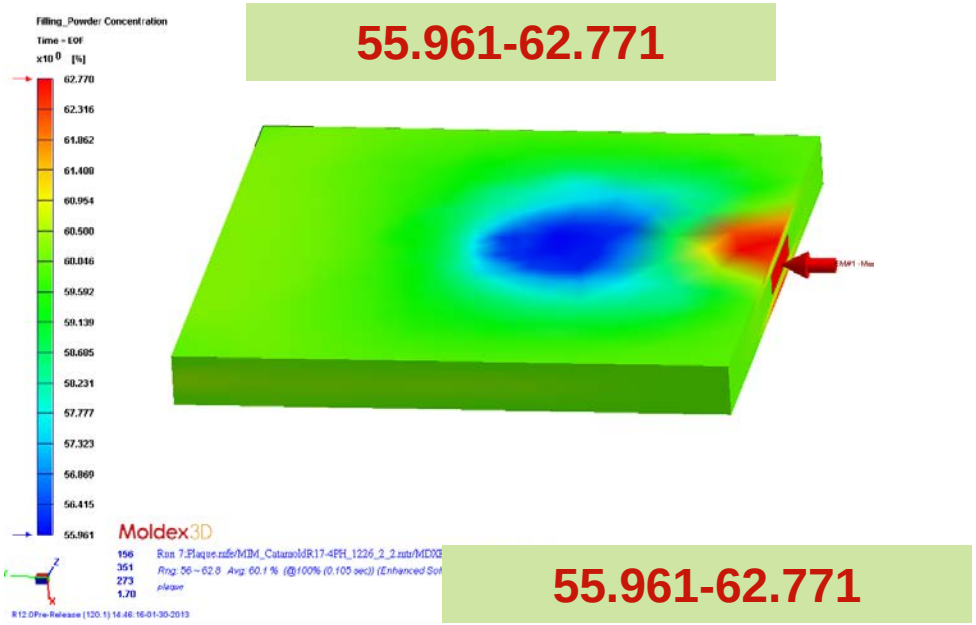


縮短Filling Time (0.1sec->0.25sec)

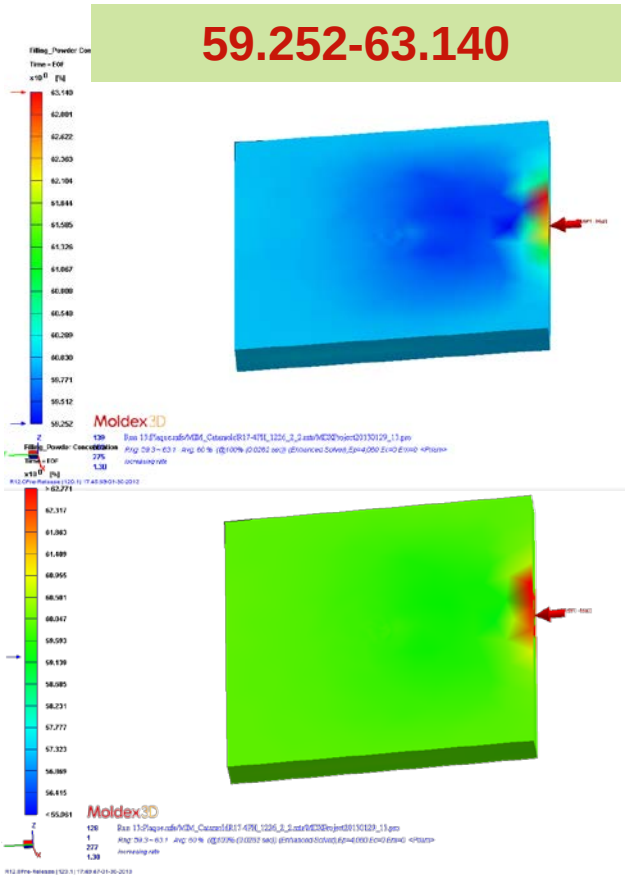
Moldex3D

> 當filling time縮短, 造成表面濃度範圍擴大, 可能產生黑線區變大

Filling time: 0.1 sec
Molding Temperature = 50 °C



Filling time: 0.025 sec
Molding Temperature = 50 °C

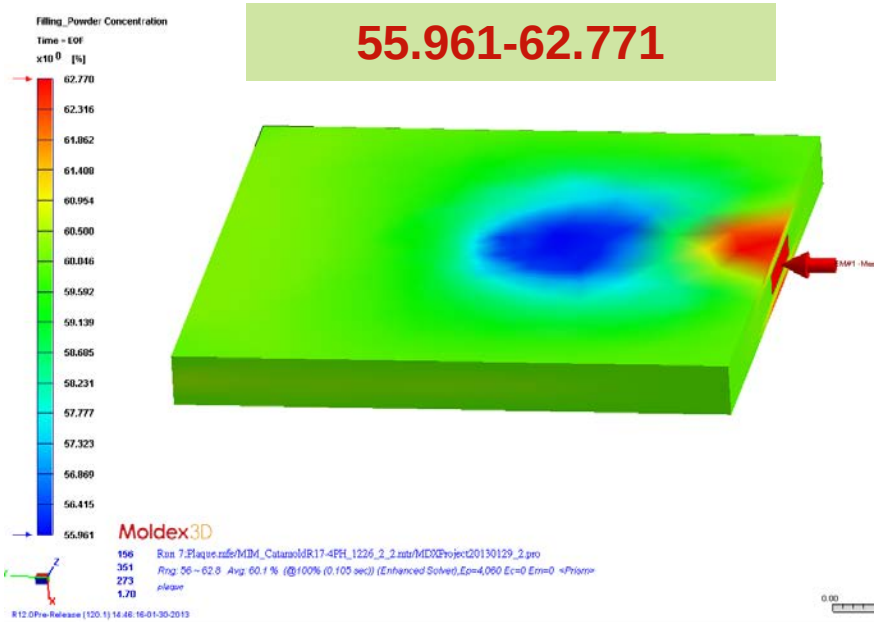


增加模溫(50K->150K)

Moldex3D

> 當模溫增加, 表面的黑線與澆口附近的濃度不均勻都消失

Filling time: 0.1 sec
Molding Temperature = 50 °C

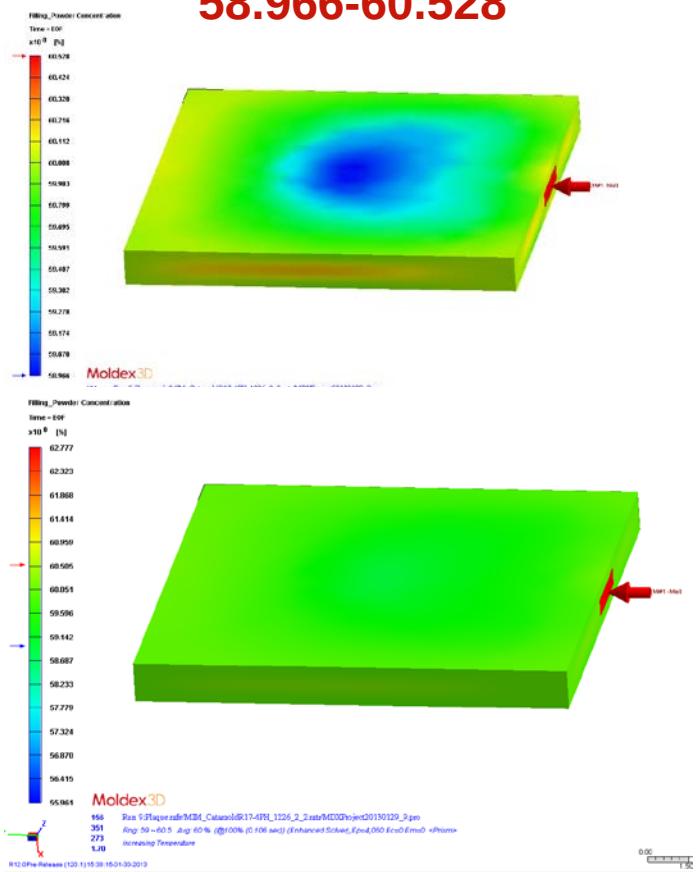


55.961-62.771

55.961-62.771

Filling time: 0.1 sec
Molding Temperature = 150 °C

58.966-60.528



結論

- PIM 能提供新的工藝 讓現代的我們能整合複雜外觀與高難度產品
- 但 PIM 製程與產品開發面臨許多挑戰
  - 品質與量產:
    - 外觀: 黑線
    - 精度與收縮
  - 處理上: 單靠人員經驗 常緩不濟急 → CAE 科學化技術需求日益殷切
- 品質與量產之掌握與控制
  - 從製程上:
    - 從 1st stage: Green part → 2nd stage: Brown part → 3rd stage: sintering
  - 1st stage: Green part 成型機理與影響

結論

- CAE 科學化技術應用於 PIM
  - Moldex3D 也投入多時
  - 歷練許多學理粹鍊與實務案例挑戰
- PIM 產業新一代開發的開發 須要大家一起投入 一起成長

Moldex3D

Thank you for your attention!

CoreTech System Co., Ltd
www.moldex3D.com