IN-DEPTH STUDY FOR THE DIFFERENT PHYSICAL MECHANISM BETWEEN OVER-MOLDING AND CO-INJECTION MOLDING

*Che-Ping Lin1, Shih-Po Sun1, Chao-Tsai (CT) Huang1, Kuan-Dian Chen2 and **Shi-Chang Tseng2***

1. CoreTech System (Moldex3D) Co., Ltd., ChuPei City, Hsinchu County, 302, Taiwan
2. National Yunlin University of Science and Technology, Yunlin, 640, Taiwan

Outline

> Introduction
> Problem and Challenge
> Objective of this study
> Results and discussions
> Conclusion and future works

What is MCM?

> Multi-component molding (MCM) is a process in which two or more materials are added to a mold to produce molded objects.

> Characteristics
   – Multi-color / multi-material components
   – Skin-core arrangement components
   – In-mold assembled components
   – Selective-compliance components
   – Soft-touch components

Insert molding

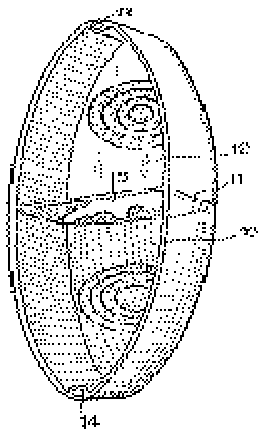
Over molding

Co-injection

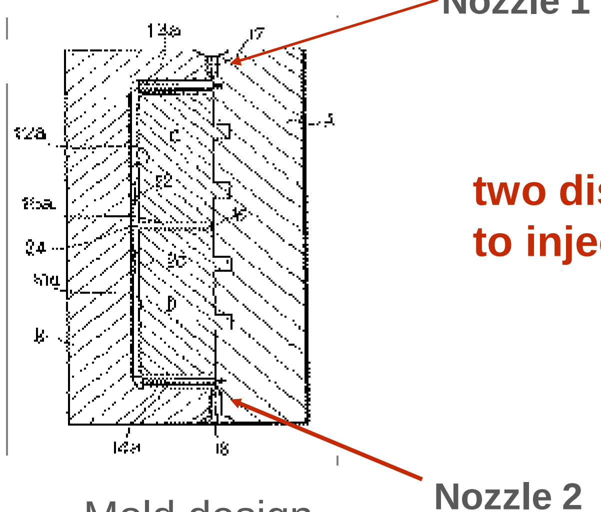
Bi-injection

History of Multi-component Molding (MCM)

- 1962: first MCM was developed by G. Carozzo "… manufacture of composite articles …"
- 1970's: co-injection molding was developed.
- 1980's: overmolding was developed.
- Till now: various new technologies proposed



MCM tailing light



two distinct nozzles used to inject the two materials

Mold design

Source: Patent #3,051,994

General Examples of MCM Products

> Consumer products

Gillette's Mach 3 Razor
Source: *http://www.glscorporation.com/docs/gillette.pdf*

- Cosmetics packaging

Source: http://www.devicelink.com

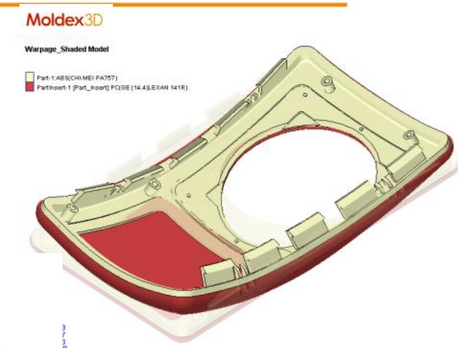
- Automotive components
  - Automotive lenses
  - Automotive door look housing
  - Pneumatic power lock components
  - Co-injected bumper fascias
  - Overmolded door handles

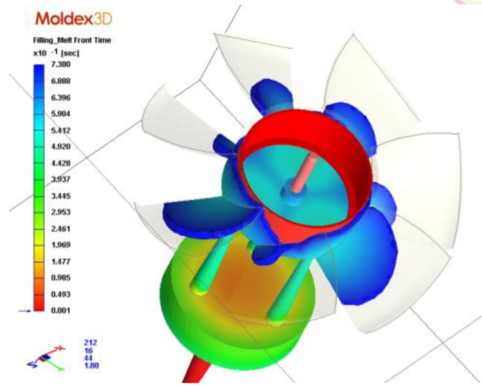
- In-Mold Assembled products

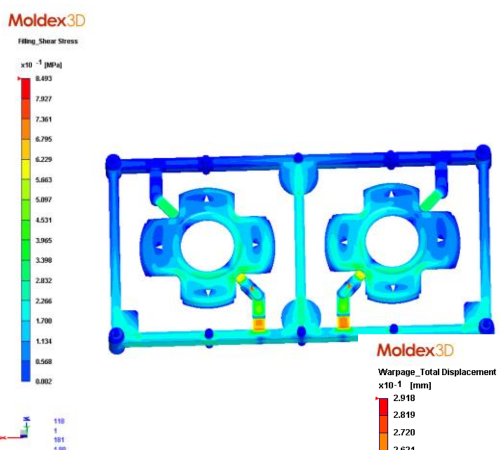
Source: http://www.fickenscher.com/

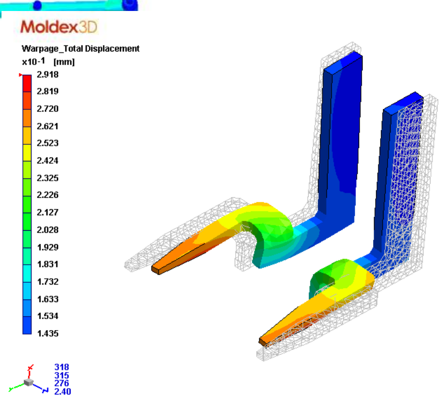
Common Problems

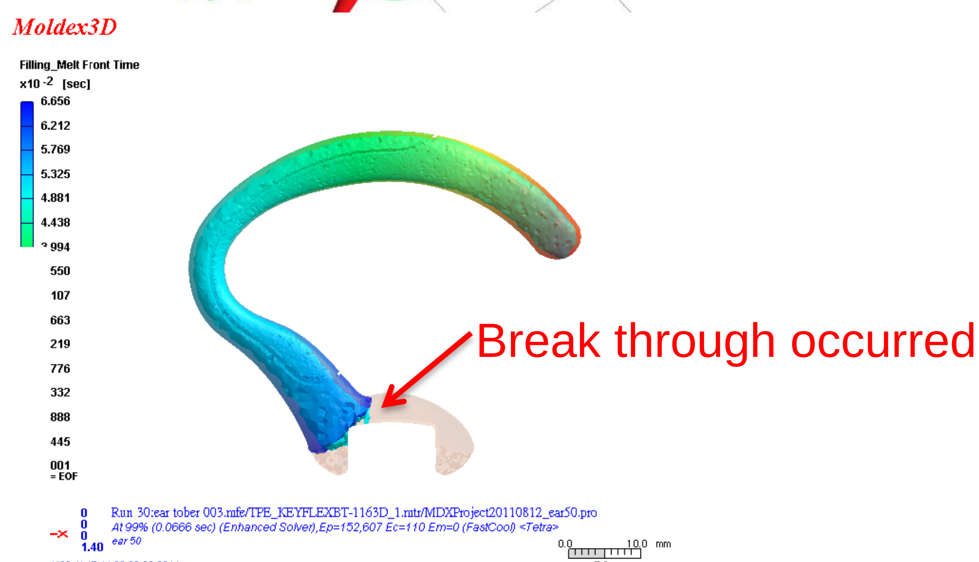
- > Different warpage mechanism
- > Poor dimensional control
- > Insert dislocation or shift
- > Residual stresses problem
- > Re-melted or wash-out
- > Break through









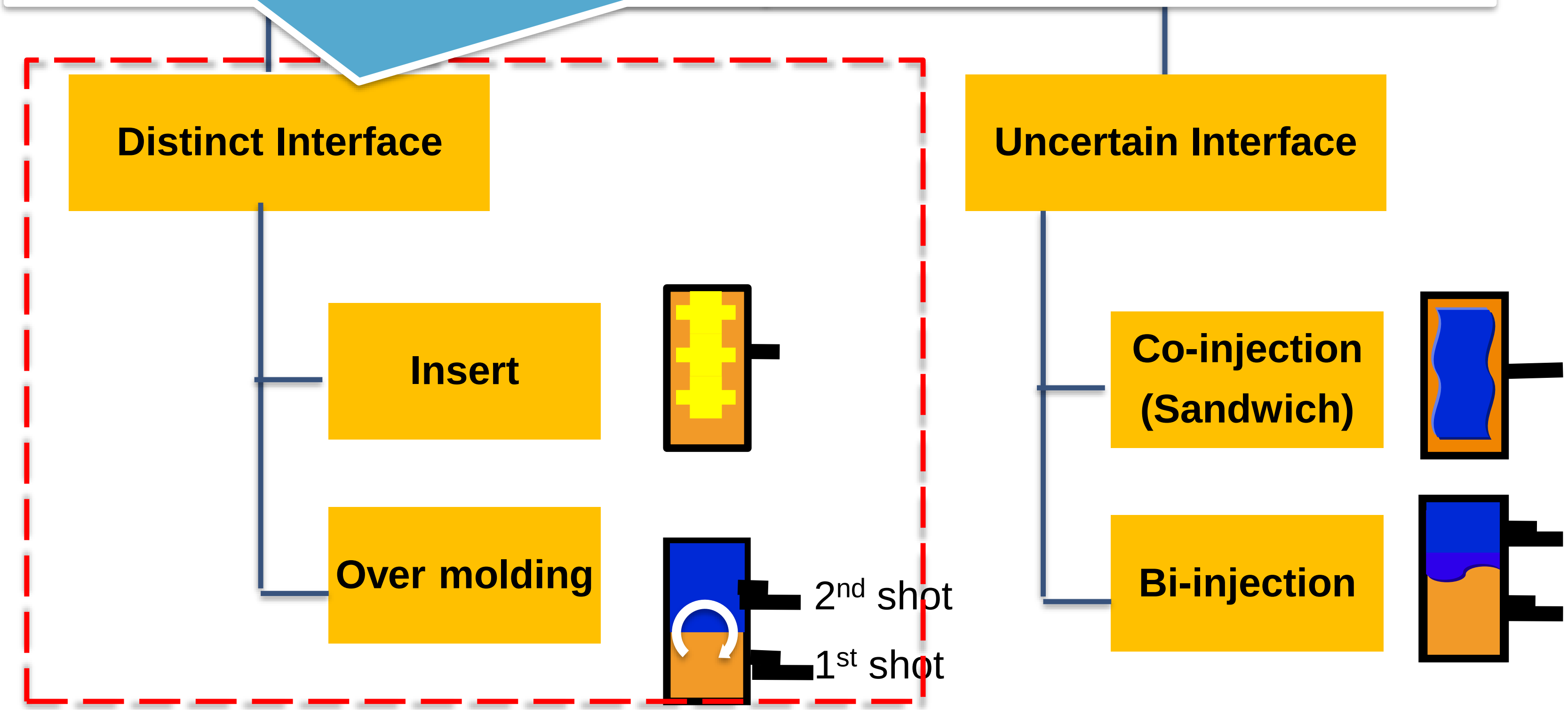


Multi-Component Molding Family

We divided the MCM into two parts, Distinct Interface and Uncertain Interface.

The Distinct Interface contain insert and over molding. Its most important feature is fixing interfaces among components. And the interface shapes are decided by mold.

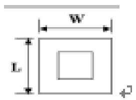
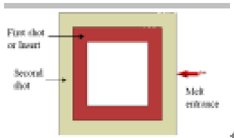
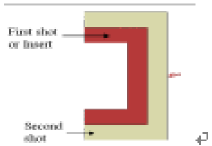
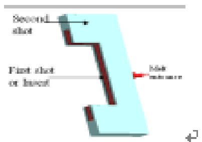
On the other hand, the UncertainInterface contains co- and bi- injection. Its feature is flexible interface which is decided by plastic flow.

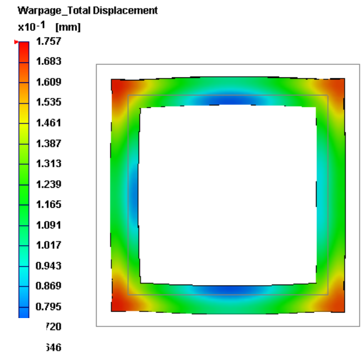


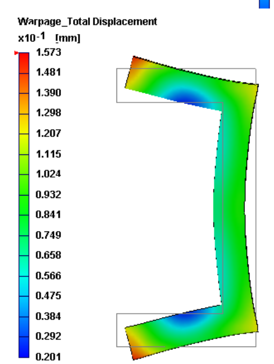
Previous Studies in MCM

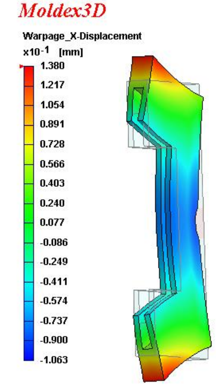
> Year 2006: ANTEC2006

– CT Huang et al, "GEOMETRICAL EFFECT AND MATERIAL SELELCTION IN MULTI-COMPONENT MOLDING (MCM) DEVELOPMENT"

Geometrical Structure	Dimension in shot[α]		Material in shot		Injection processes focused[β]
	1st	2nd	1st	2nd	2nd shot
Square type 	L=19 W=19 T=2 (mm)	L=25 W=25 T=2 (mm)	No Cu Mg LDPE	ABS	F/P/C/W
U type 	L=19 W=9.5 T=2 (mm)	L=25 W=12.5 T=2 (mm)	No Cu Mg LDPE	ABS	F/P/C/W
Dual U type 	L=19 W=9.5 T=1 (mm)	L=25 W=12.5 T=2 (mm)	No Cu Mg LDPE	ABS	F/P/C/W

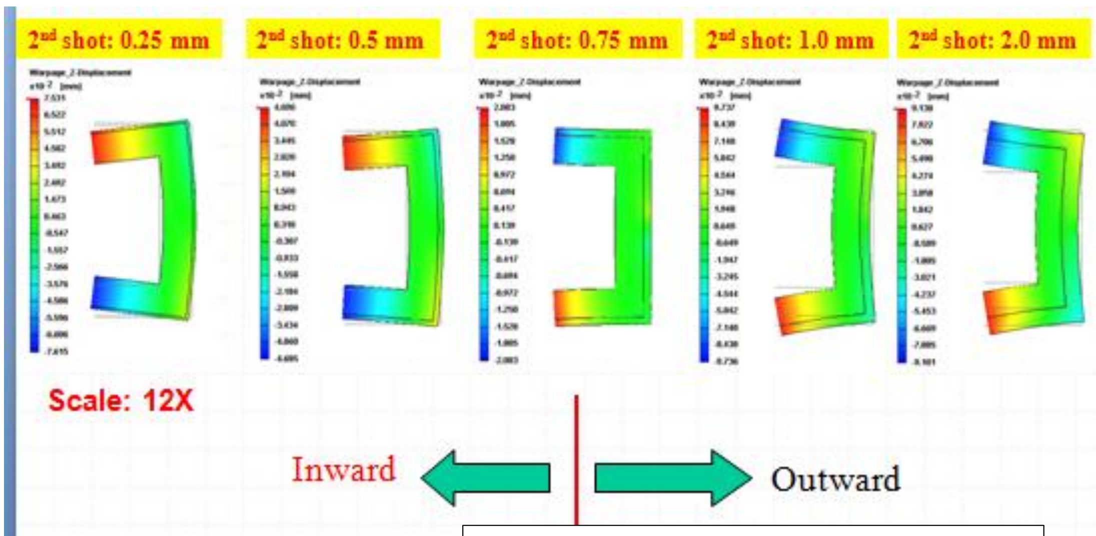


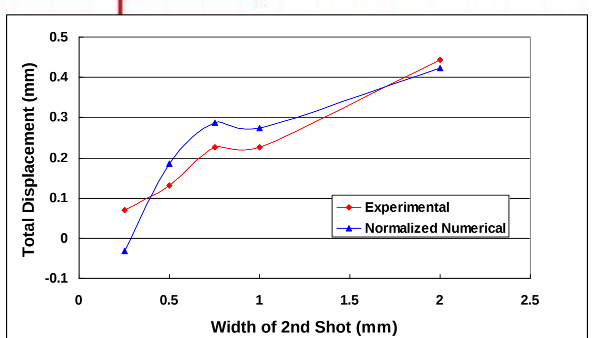


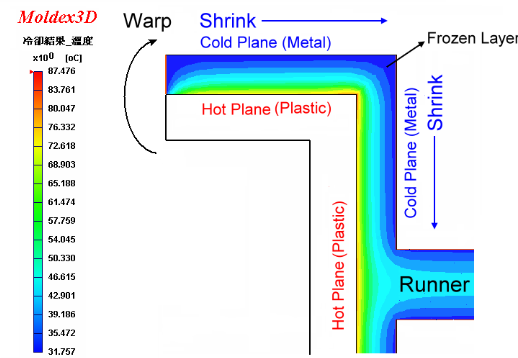


Previous Studies in MCM

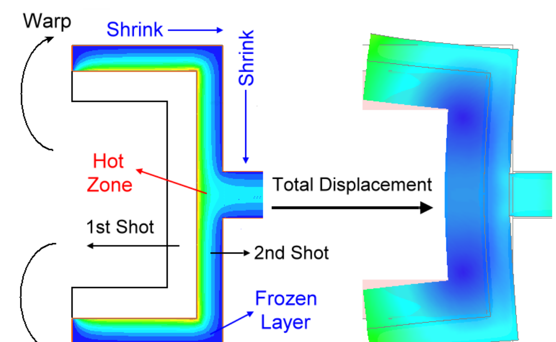
> Year 2007: ANTEC2007
  – CT Huang et al, "Investigation on Warpage and Its Behavior in Sequential Overmolding"







(a)

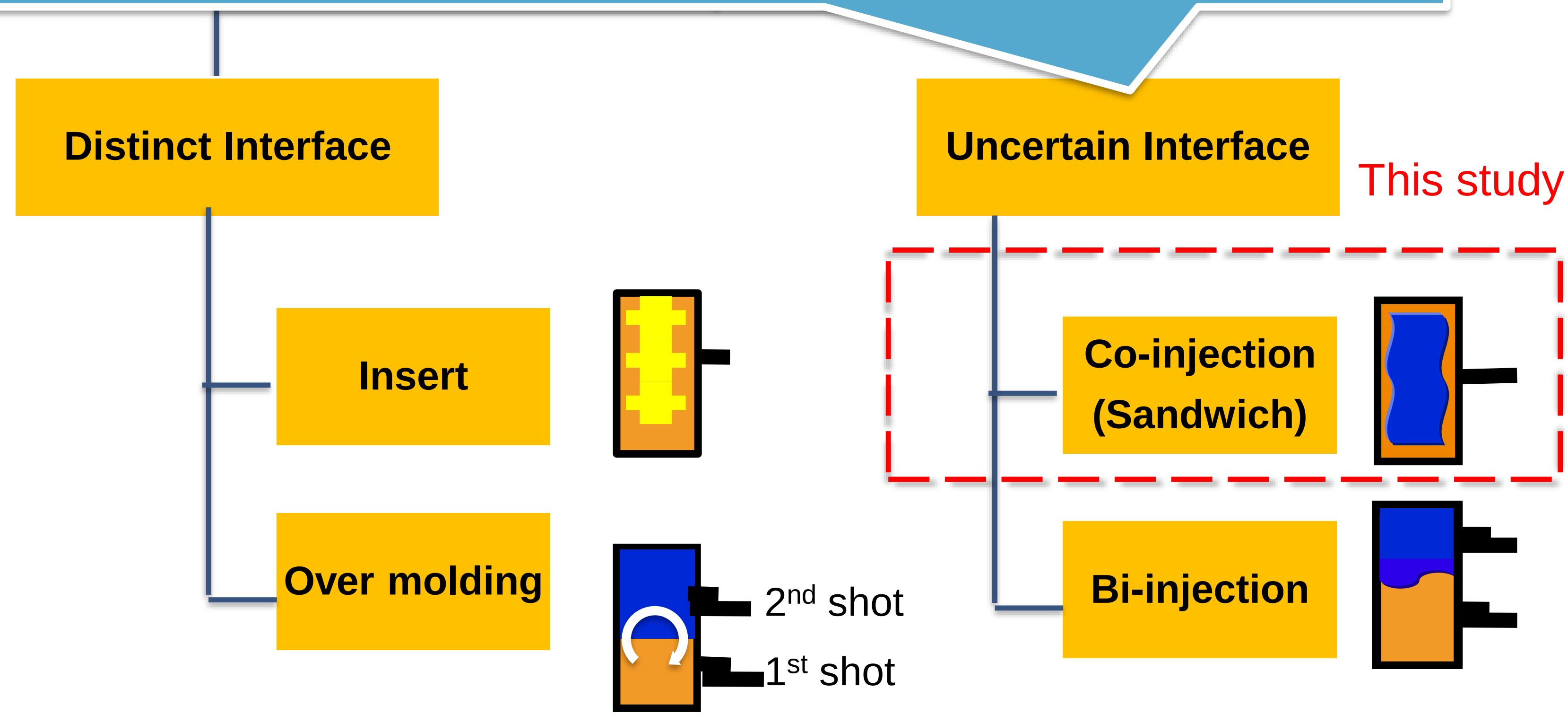


(b)

Multi-Component Molding Family

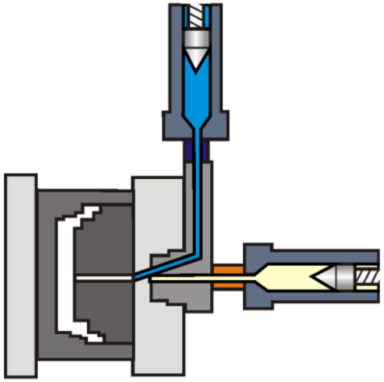
The bi or co injection on the other hand has an uncertain interface in between. This poses difficulties and challenges. This is especially important for structural applications of which product stiffness depends largely on the skin/core distribution.

Unlike the insert or over molding which has a distinct interface, skin/core interfacial flow front of co-injection molding cannot be controlled with ease.

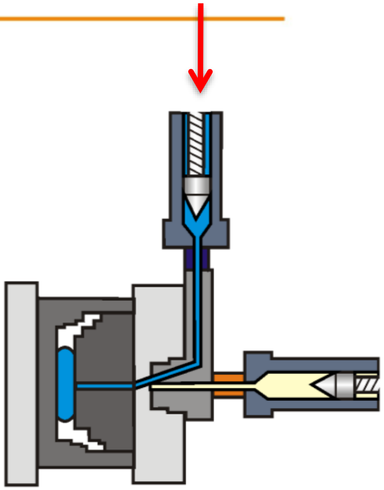


Stages

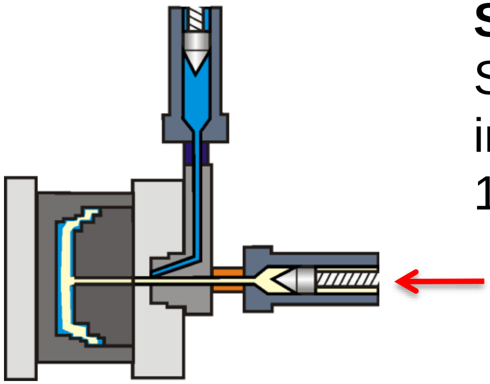
Step 1
Empty cavity
1st shot (skin): blue
2nd shot (core): yellow



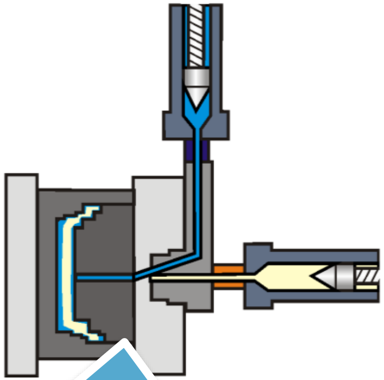
Step 2
Skin injection



Step 3
Core injection



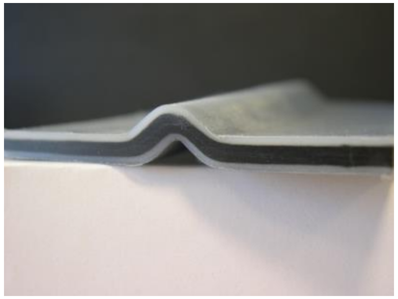
Step 4
Second skin injection for 1-2-1 structure



an ideal co-injection molded part exhibits a core completely encased by the skin except for the regions near the gate.

Benefits of using co-injection molding

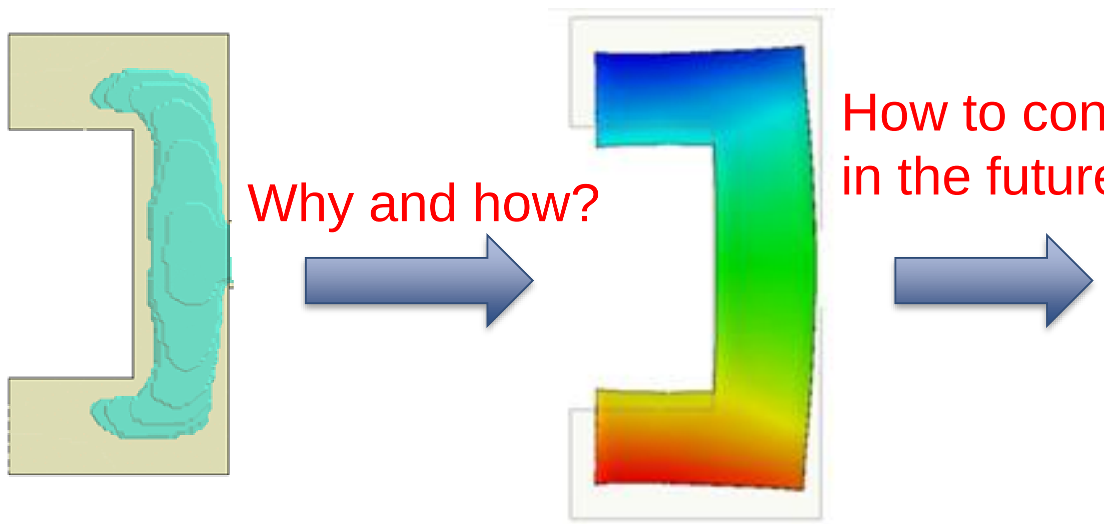
- Recycled core reduces costs
- Recycled core reuses waste
- Engineering core structure, e.g. fiber foaming, enhances product strength or performance; virgin skin provides quality aesthetic finish for recycled or engineering core
- Elastomer skin improves surface touch
- No increase on cycle times comparing to sequential or multi-component molding



Challenges and Problems

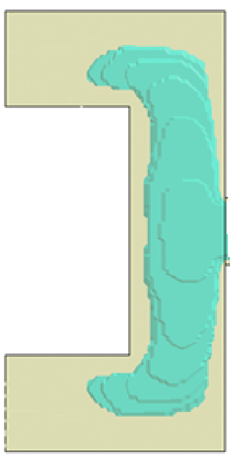
> Regarding co-injection process

- Many control factors need to focus
  - Material combination and their properties?
  - Core/skin ratio? Blow through vs Warpage control.
  - Process conditions?
- Based on quality specification, what is the physical mechanism?

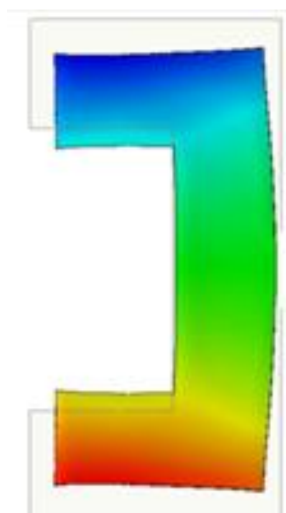


Objective of this Study

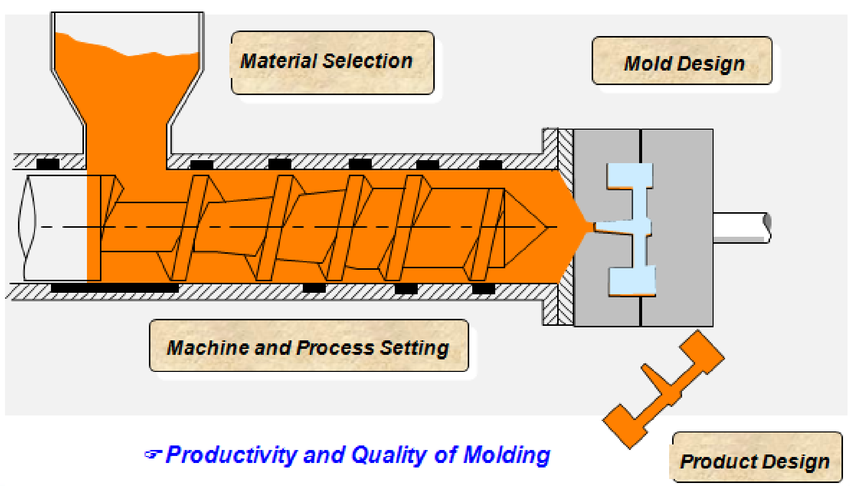
> What is the warpage behavior for co-injection process
  - Core ratio effect
  - Process condition effect
  - Warpage mechanism



Study why and how?



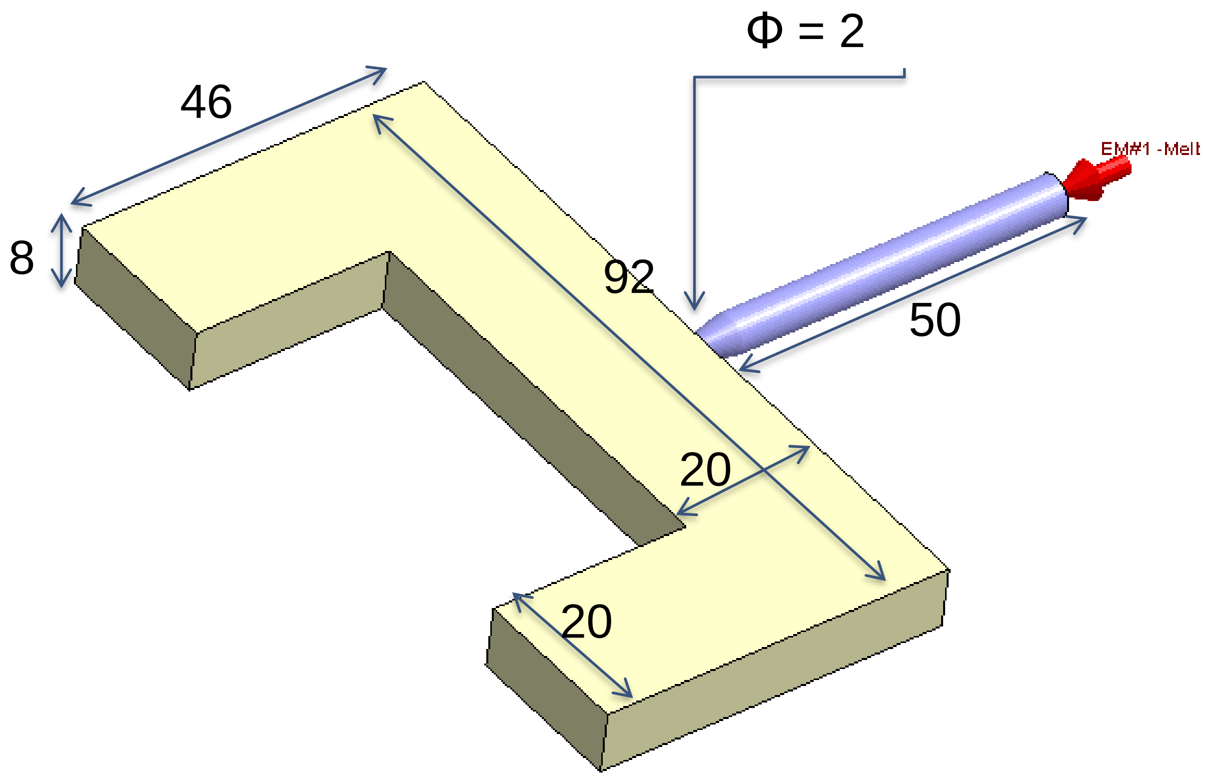
Try to figure out the integration



Numerical Investigation for Co-injection molding

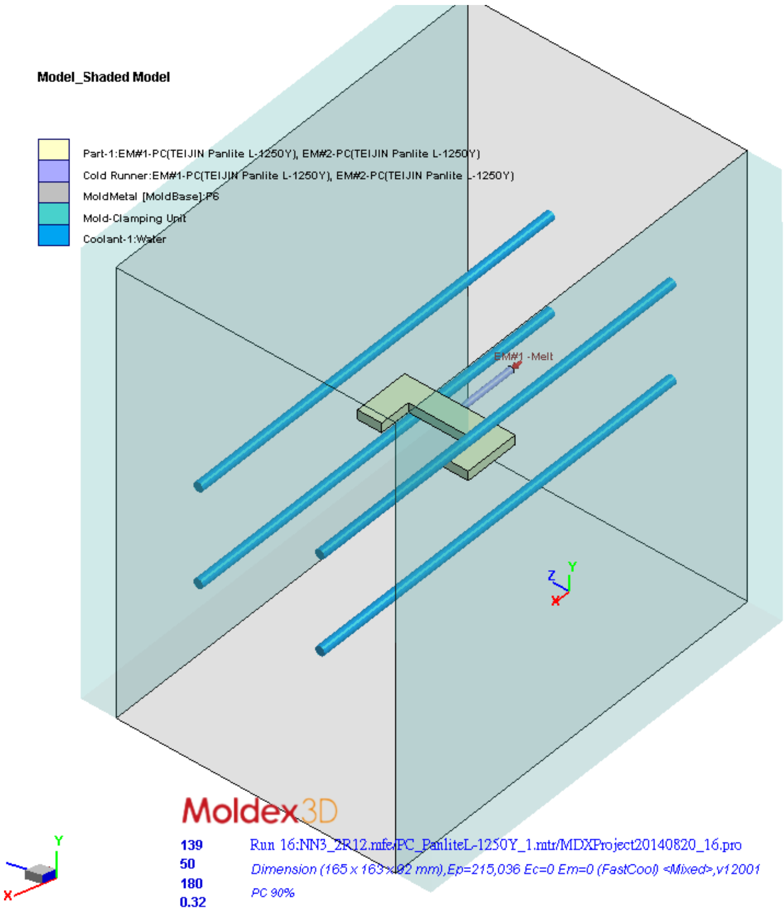
A Standard Part

> **Input Mesh**



Unit: mm
Part Volume: 23,040 mm^3

Model Information



- Mesh Technology: Hybrid
- Element Count: 215,036

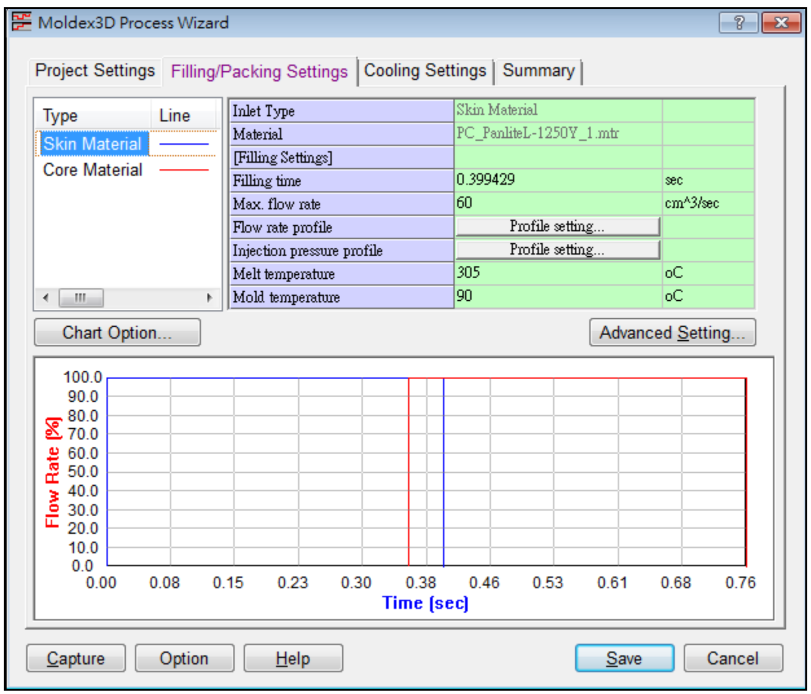
> Part Dimension
- L92.0x W46.0 xH8.0mm
- Volume: 23.04 C.C.

> Material
- PC Panlite L-1250Y

> Condition
- Filling Time: 0.39942 sec
- Melt Temp.: 305 ℃
- Mold Temp.: 90 ℃

Operating Condition

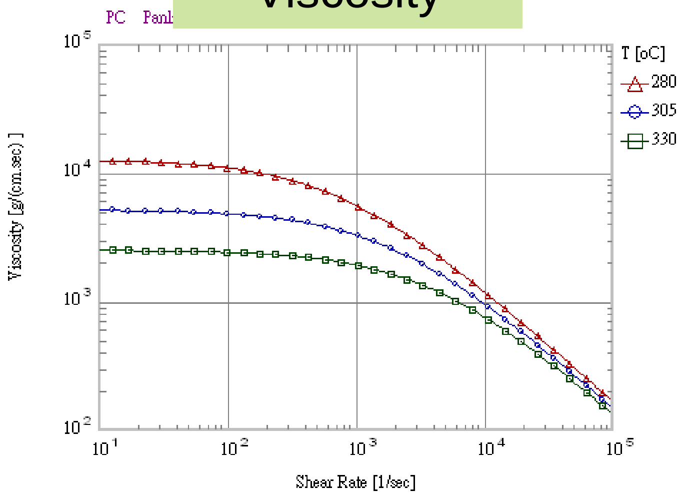
- Melt Temperature: 305 ºC
- Mold Temperature: 90 ºC
- Filling Time = 0.39942 sec



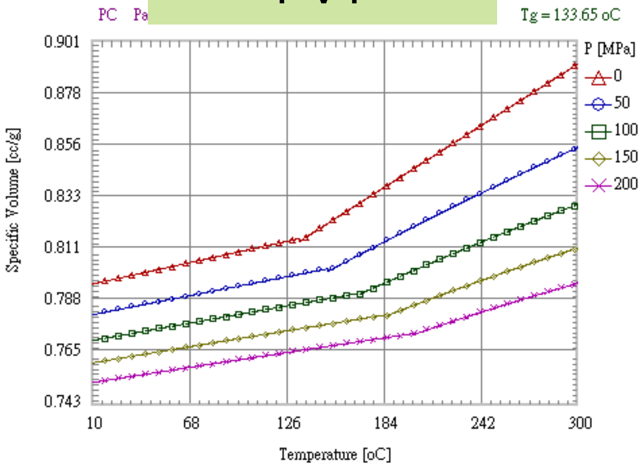
[Filling]	
Filling time (sec)	0.399429
Melt Temperature (oC)	305
Mold Temperature (oC)	90
Maximum injection pressure (MPa)	222
Injection volume (cm^3)	23.9657
[Packing]	
Packing Time (sec)	0
Maximum packing pressure (MPa)	150
[Cooling]	
Cooling Time (sec)	20
Mold-Open Time (sec)	5
Eject Temperature (oC)	133.65
Air Temperature (oC)	25
[Miscellaneous]	
Cycle time (sec)	25.3994
Mesh file	NN3_2R12.mfe
Material file	PC_PanliteL-1250Y_1.mtrPC_Panl...

Material Properties

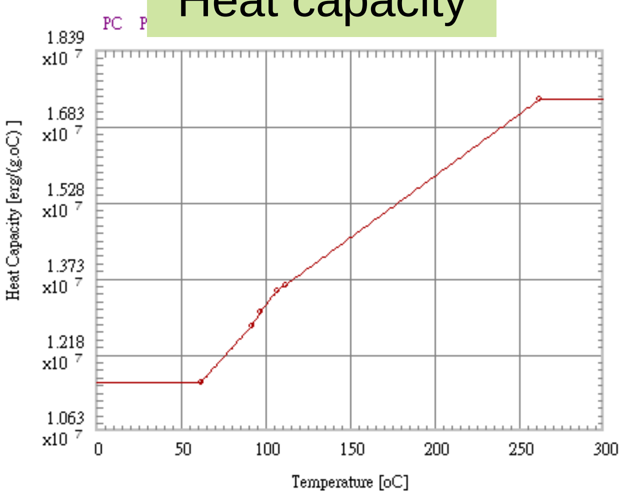
Viscosity



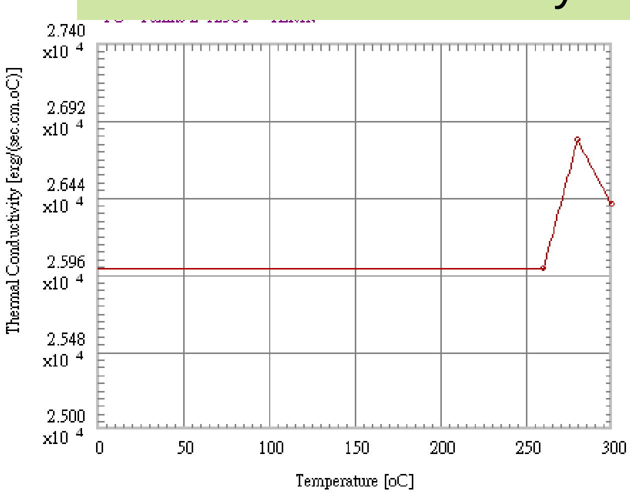
PVT



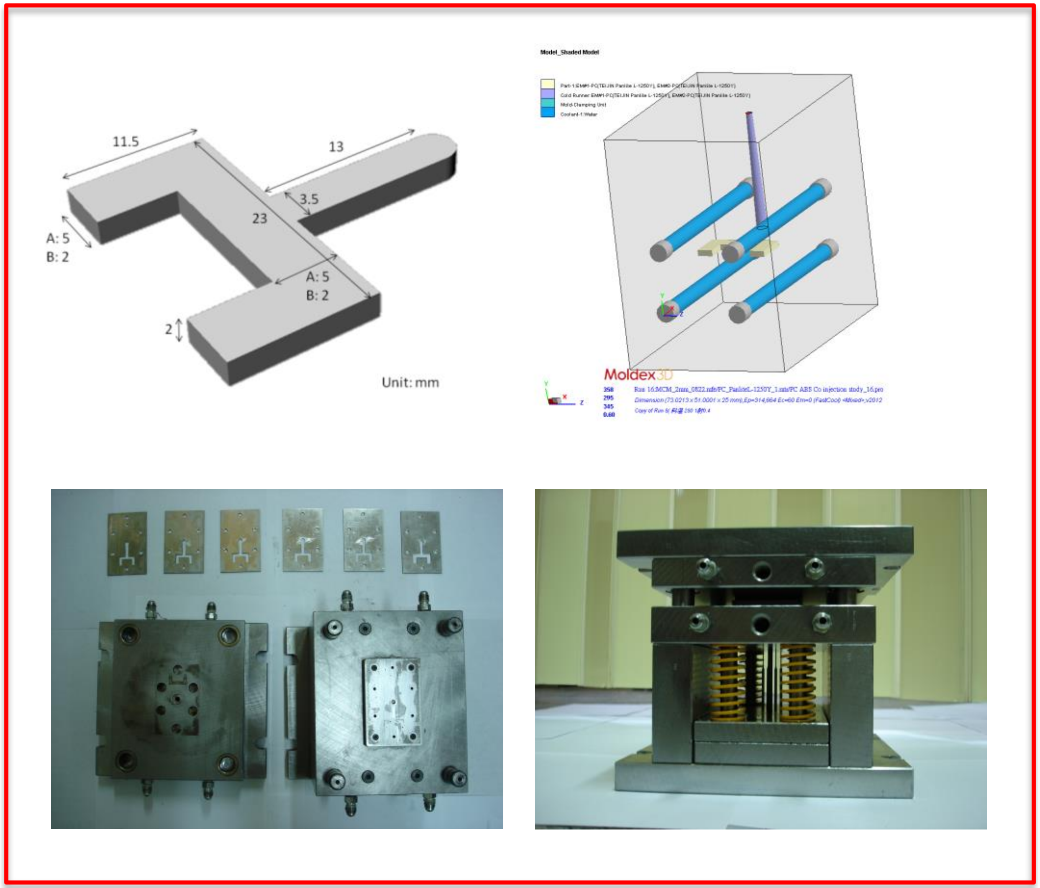
Heat capacity



Thermal conductivity



Experimental Setup for Co-injection Molding

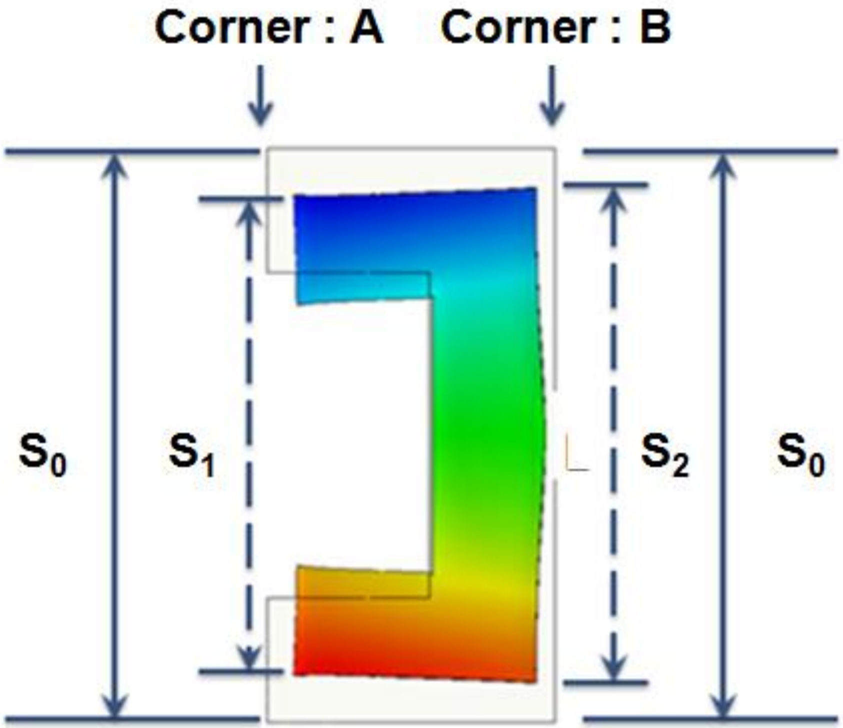


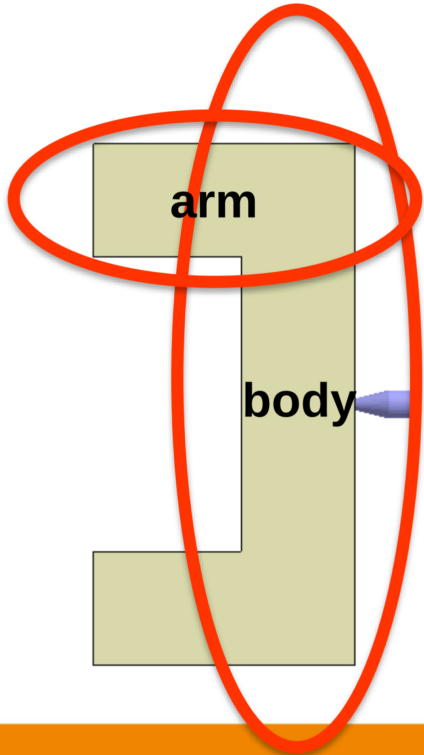
New injection molding system for Co-injection

Co-injection mold system

Definition for Warpage Behavior

> Warpage behavior definition for Inward or Outward:
  - at Corner A, when $S_1 < S_0$, it is inward, where S_0 is the original design length;
  - at Corner B, when $S_2 < S_0$, it is Inward.
  - As S2>S1, it is inward for two arms.

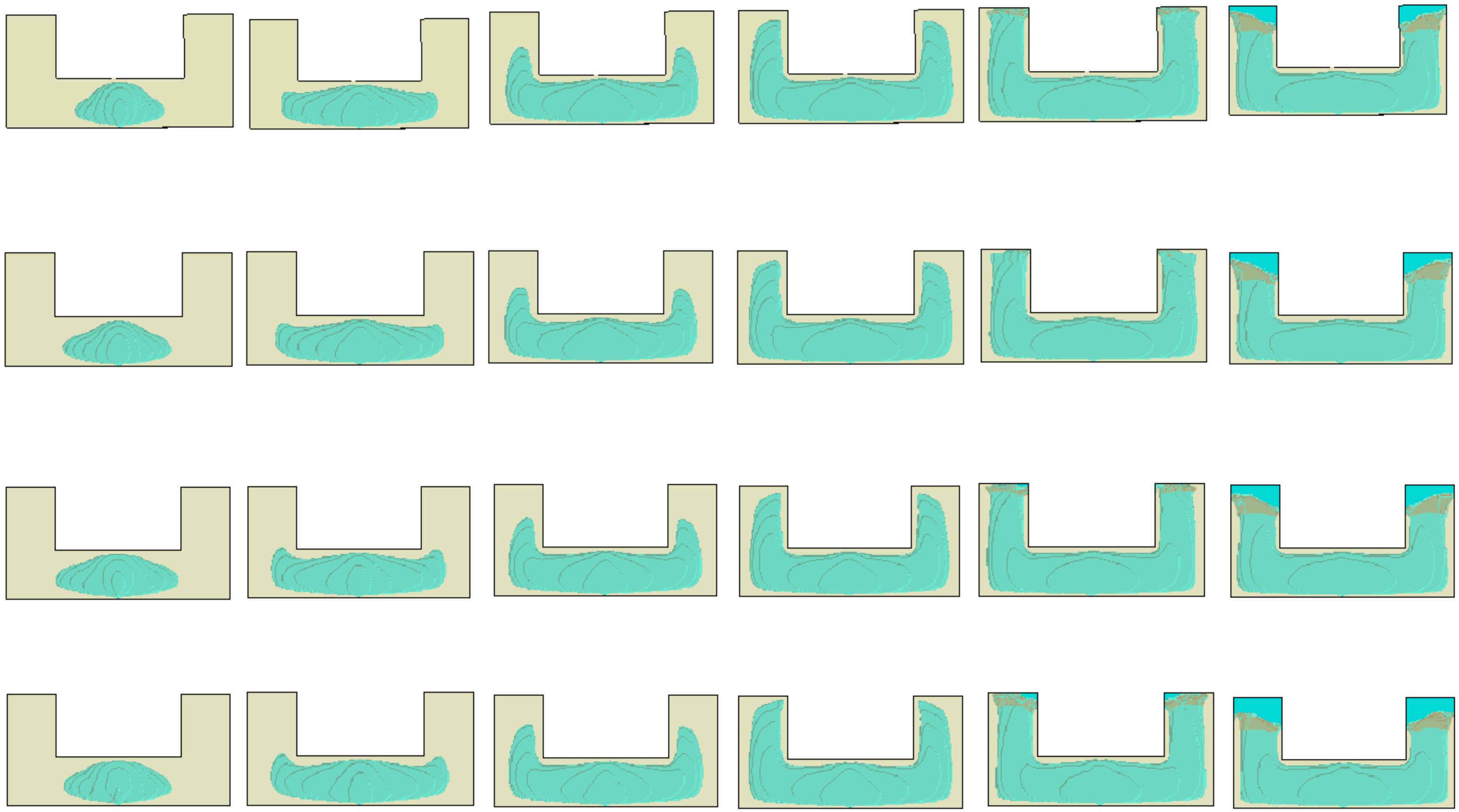




Process Conditions

	Shot	Material	Flow rate	Melt temp.
Original	1st	PC	80 cc/sec	305℃
	2nd	PC	80 cc/sec	305℃
Melt temp.	1st	PC	80 cc/sec	280℃
	2nd	PC	80 cc/sec	280℃
Flow rate	1st	PC	20 cc/sec	305℃
	2nd	PC	80 cc/sec	305℃
Flow rate 2	1st	PC	20 cc/sec	305℃
	2nd	PC	20 cc/sec	305℃

Filling Behavior: Melt Front



Original setting

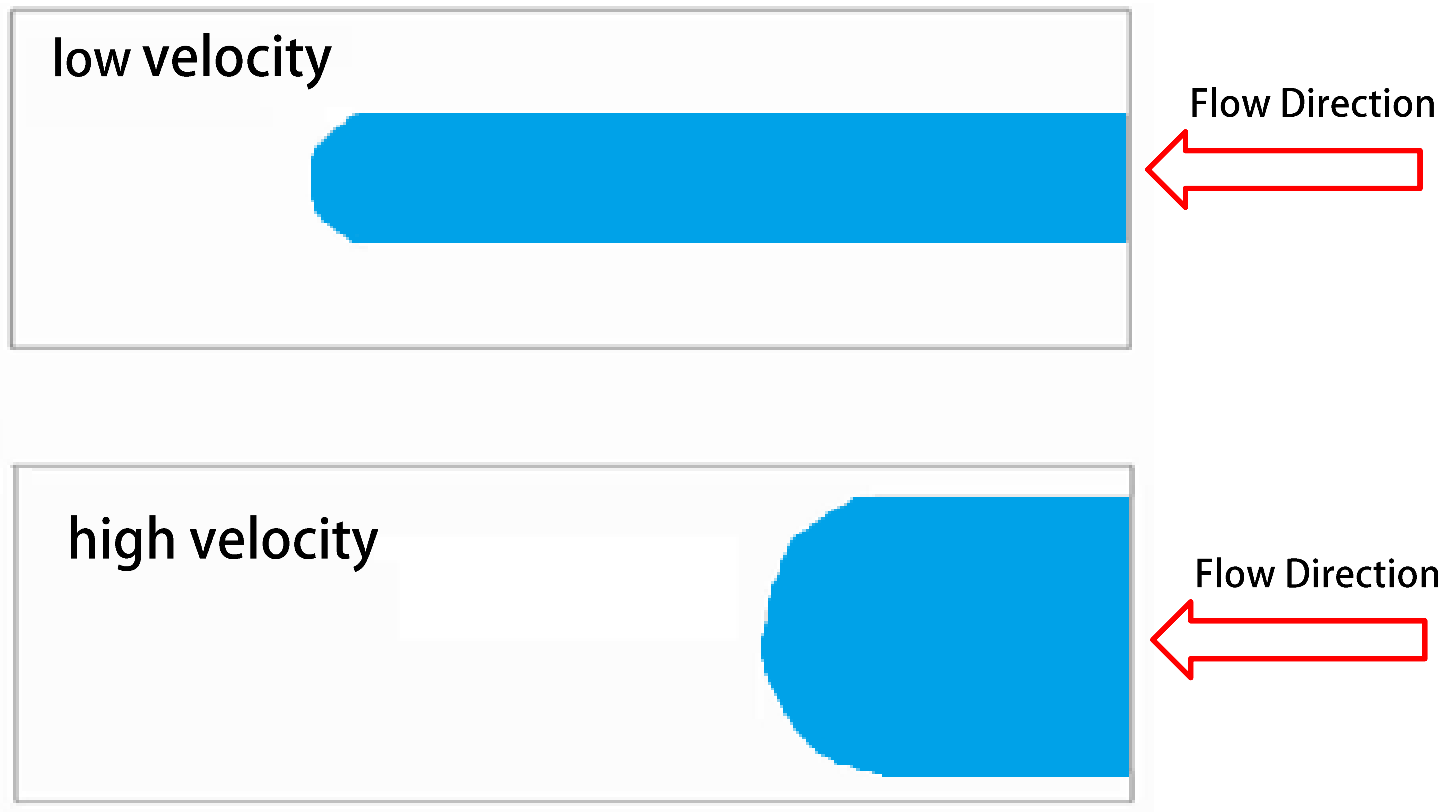
Melt temp. effect

Flow rate effect 1

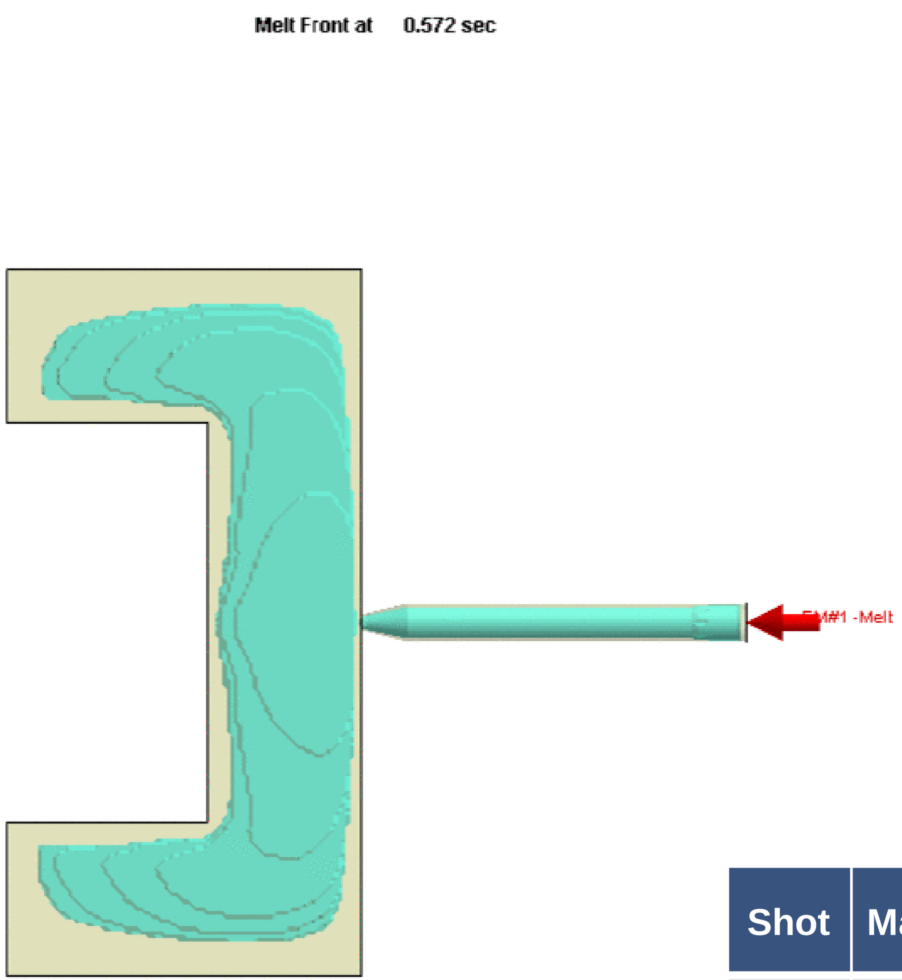
Flow rate effect 2

Core ratio 10% 20% 30% 40% 50% 60%

Research Questions - The effect of injection rate

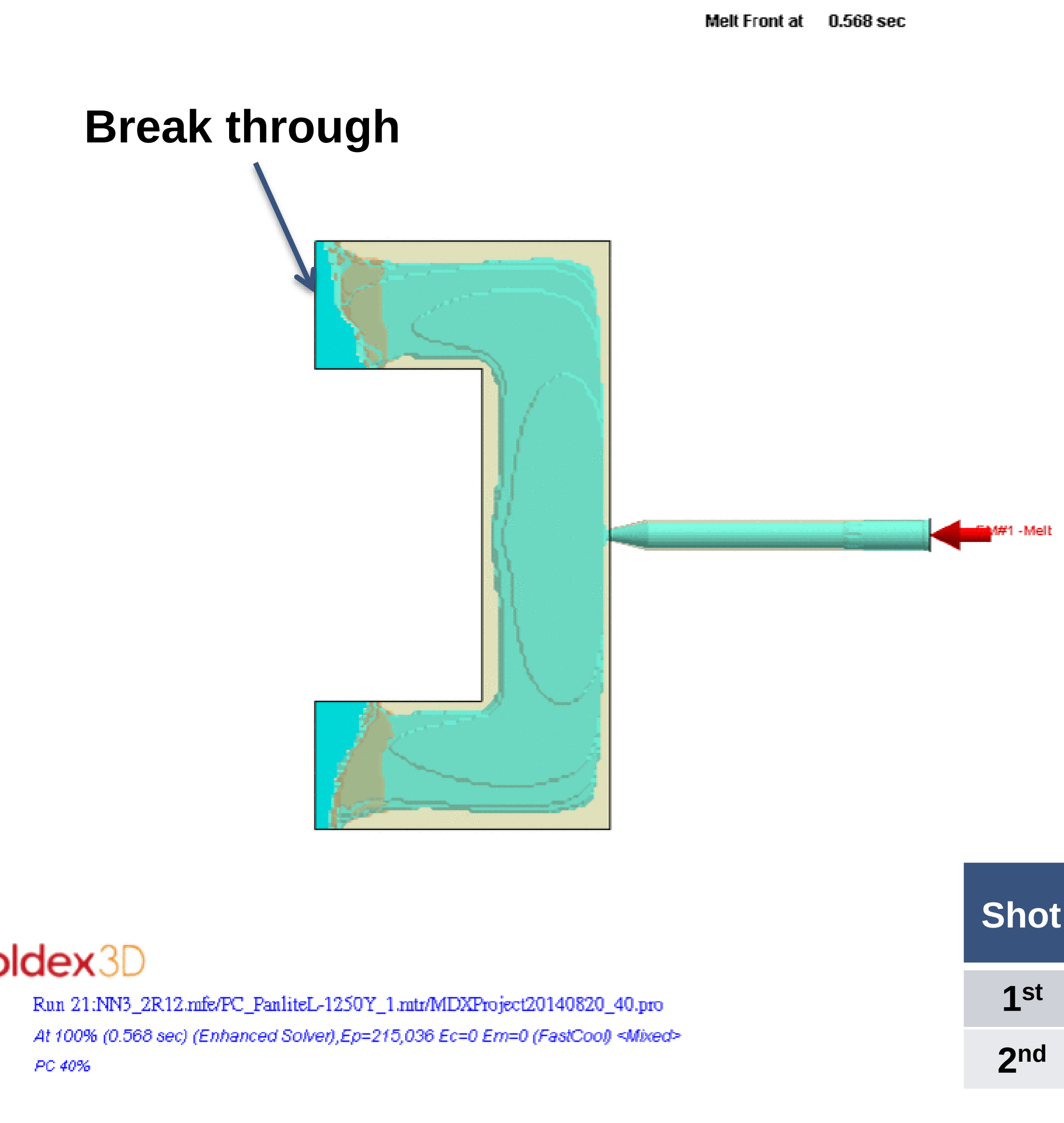


Filling _ Melt Front Animation



Shot	Material	Flow rate	Melt temp.	%
1st	PC	7 cc/sec	305℃	60
2nd	PC	7 cc/sec	305℃	40

Filling _ Melt Front Animation



Shot	Material	Flow rate	Melt temp.	%
1st	PC	7 cc/sec	305℃	40
2nd	PC	7 cc/sec	305℃	60

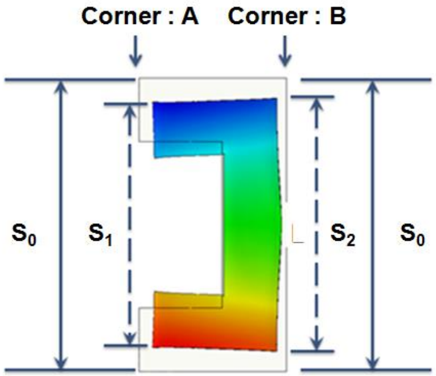
Original Test

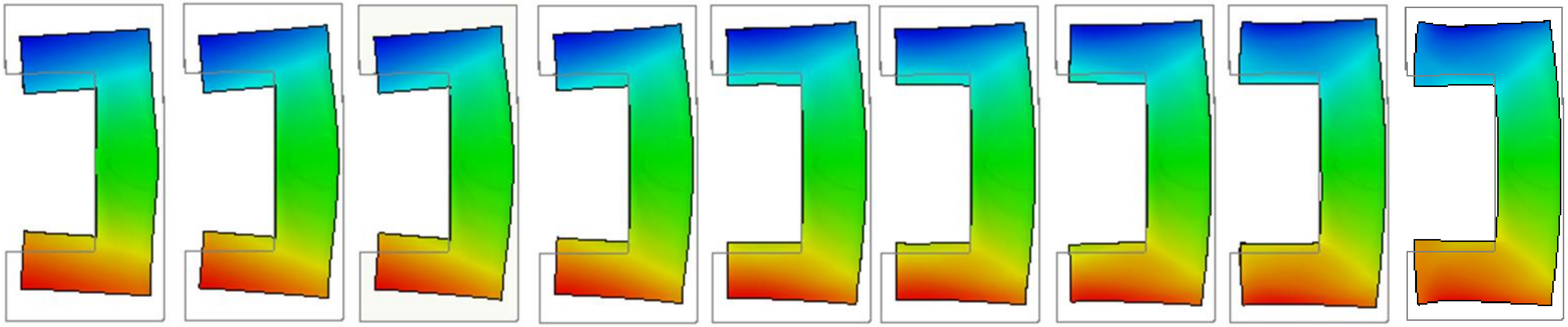
	Shot	Material	Flow rate	Melt temp.
Original	1st	PC	60 cc/sec	305℃
	2nd	PC	60 cc/sec	305℃

Moldex3D

PC/PC Material:
High Melt Temp: 305ºC and 60 cc/sec

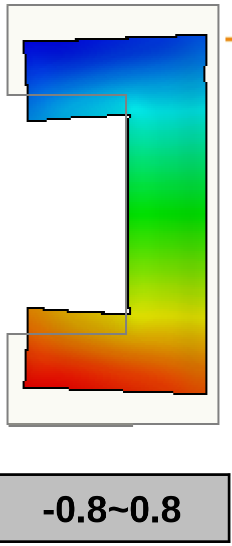
- S_0-S_1 means the warpage at corner A
- S_0-S_2 means the warpage at corner B
- And S_2-S_1 indicates the warpage trend of two arms is inward.

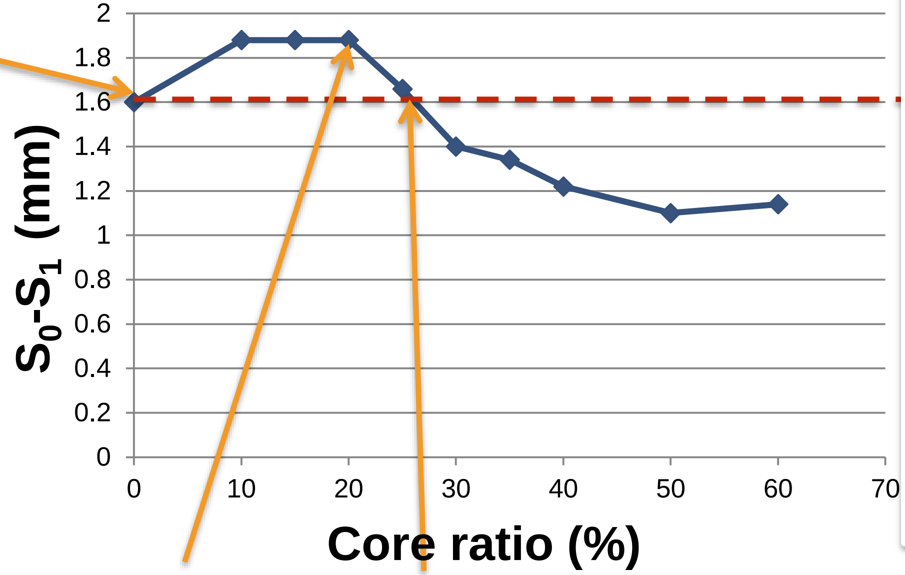




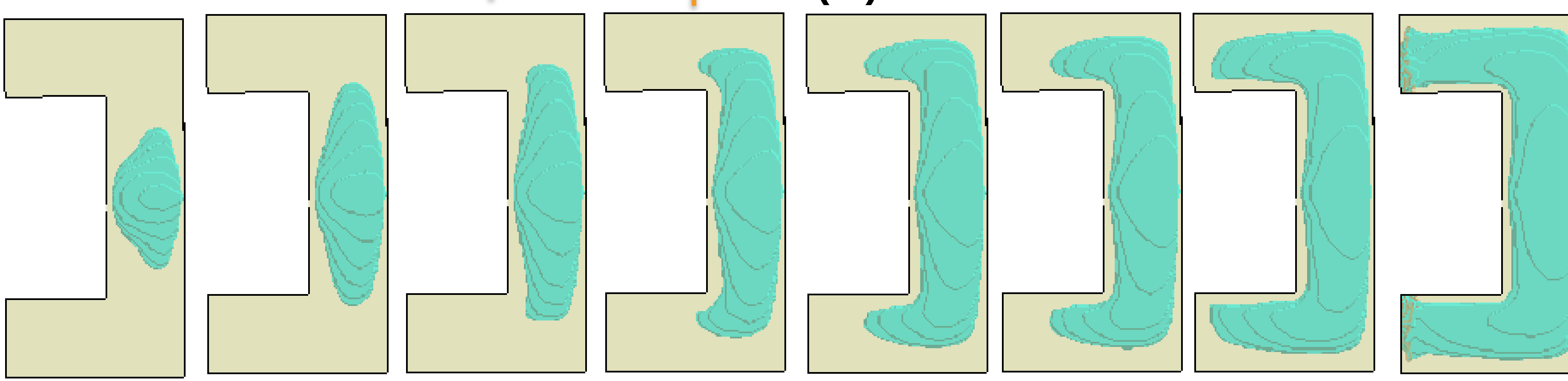
Core ratio (%)	10	15	20	25	30	35	40	50	60
S_0-S_1	1.88	1.88	1.88	1.66	1.4	1.34	1.22	1.1	1.14
S_0-S_2	1.42	1.27	1.22	1.10	0.99	0.97	0.91	0.79	0.82
S_2-S_1	0.46	0.61	0.66	0.56	0.41	0.37	0.31	0.31	0.32

Single shot (in the same condition with 1st shot)





When the core ratio is low, which means the core stays in the body, the quantity of warpage keeps the same. After the core penetrates to the two arms, the warpage decreases with the penetration rate.
Comparing to single shot, warpage starts to decrease when the core ratio reaching to 25%.
However, the improved effect decreases with the core ratio increases after the core ratio reaching to 40%.



Core 10% Ratio | 15% | 20% | 25% | 30% | 35% | 40% | 50%

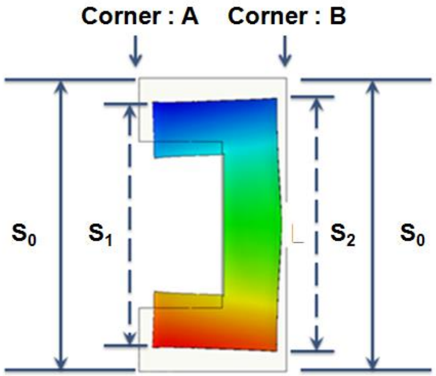
Melt Temp. Effect

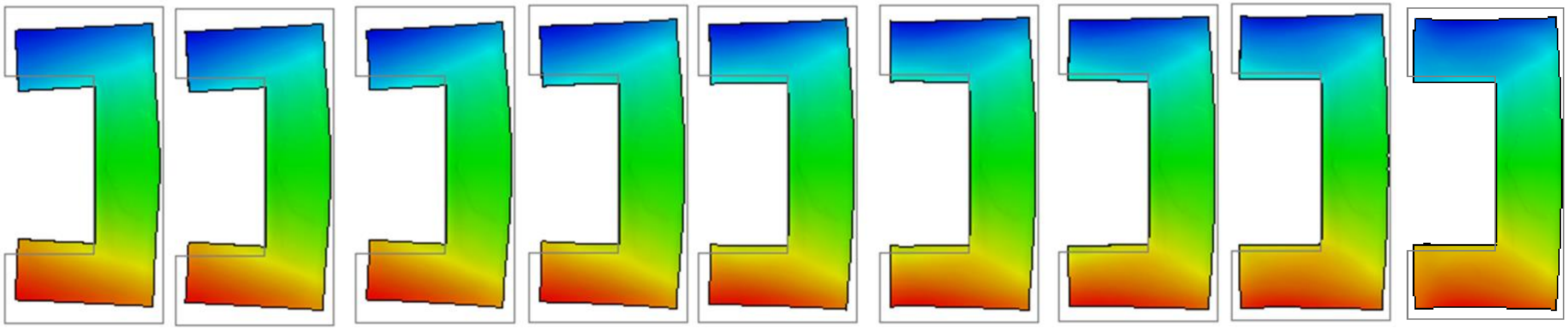
	Shot	Material	Flow rate	Melt temp.
Melt temp.	1st	PC	60 cc/sec	280℃
	2nd	PC	60 cc/sec	280℃

Moldex3D

PC/PC Material:
High Melt Temp: 280ºC and 60 cc/sec

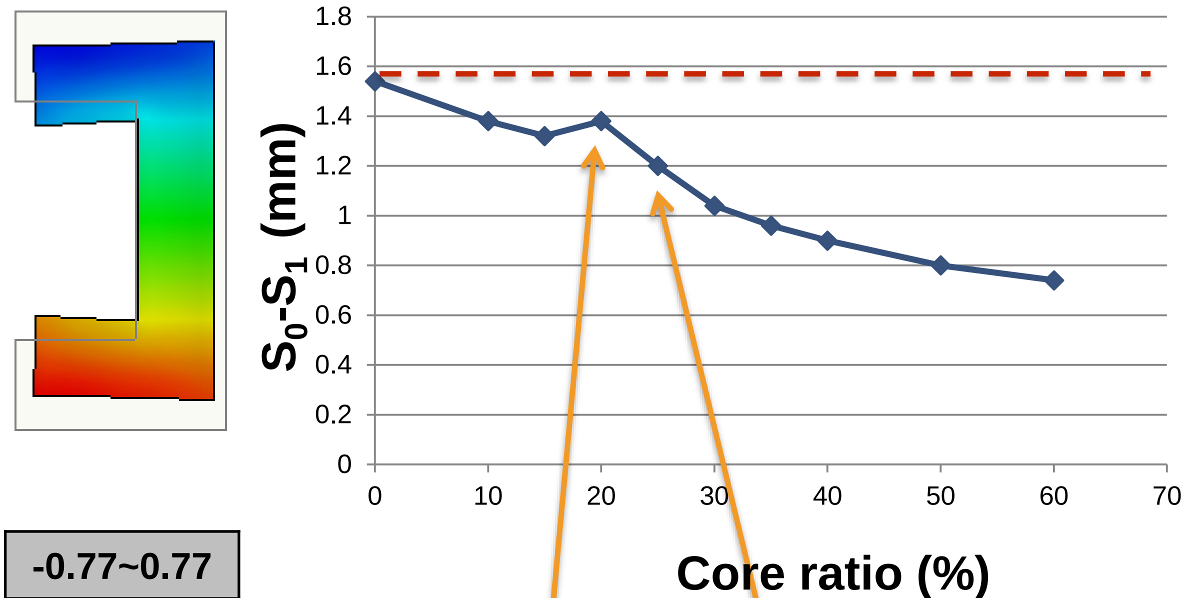
- S_0-S_1 means the warpage at corner A
- S_0-S_2 means the warpage at corner B
- And S_2-S_1 indicates the warpage trend of two arms is inward.





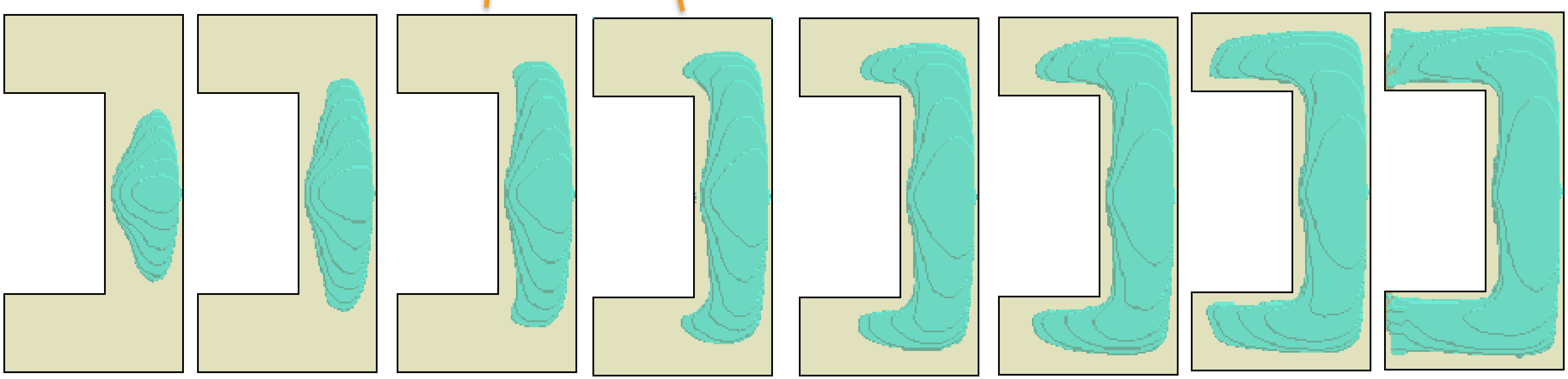
Core ratio (%)	10	15	20	25	30	35	40	50	60
S_0-S_1	1.38	1.32	1.38	1.2	1.04	0.96	0.9	0.8	0.74
S_0-S_2	0.96	0.87	0.88	0.79	0.73	0.69	0.66	0.58	0.54
S_2-S_1	0.42	0.45	0.5	0.41	0.31	0.27	0.24	0.22	0.2

Single shot (in the same condition with 1st shot)



Comparing to single shot, regardless the core ratio, the warpage is improved.

When the core ratio reaches to 25%, the warpage starts to be affected obviously. However, The effect decreases with the core ratio increases.



Core Ratio 10% 15% 20% 25% 30% 35% 40% 50%

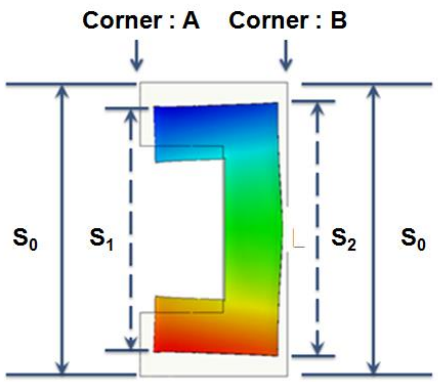
Flow rate effect 1

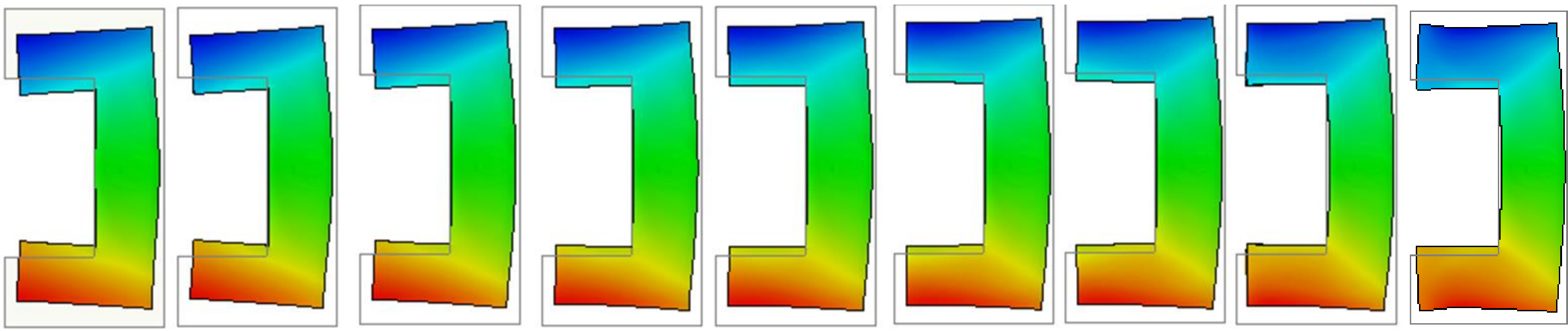
	Shot	Material	Flow rate	Melt temp.
Flow rate	1st	PC	20 cc/sec	305℃
	2nd	PC	60 cc/sec	305℃

Moldex3D

PC/PC Material:
High Melt Temp: 305°C and 20/60 cc/sec

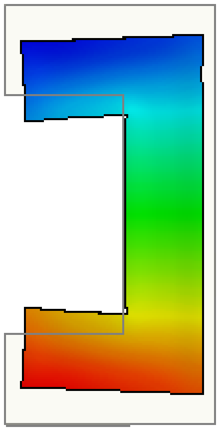
- S_0-S_1 means the warpage at corner A
- S_0-S_2 means the warpage at corner B
- And S_2-S_1 indicates the warpage trend of two arms is inward.

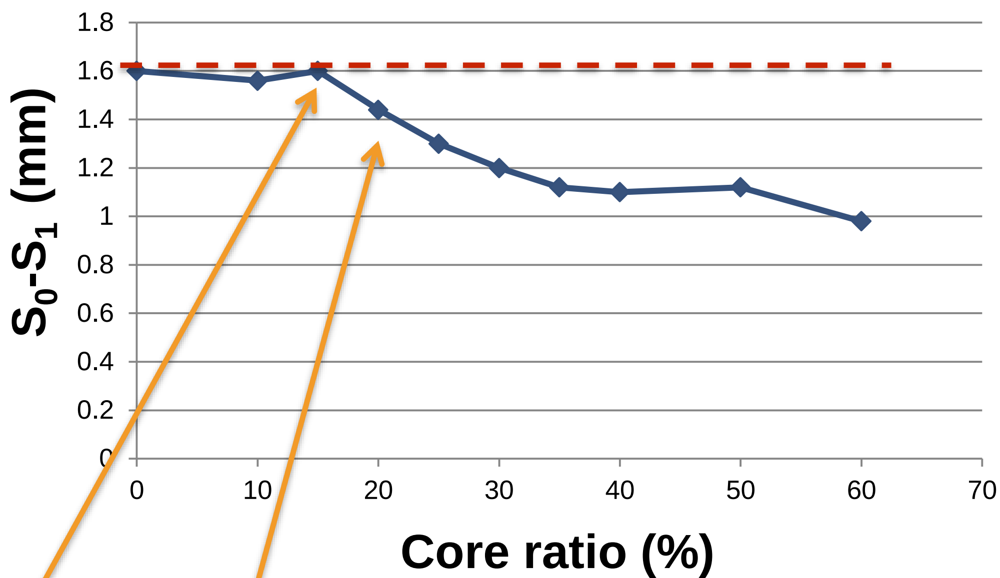




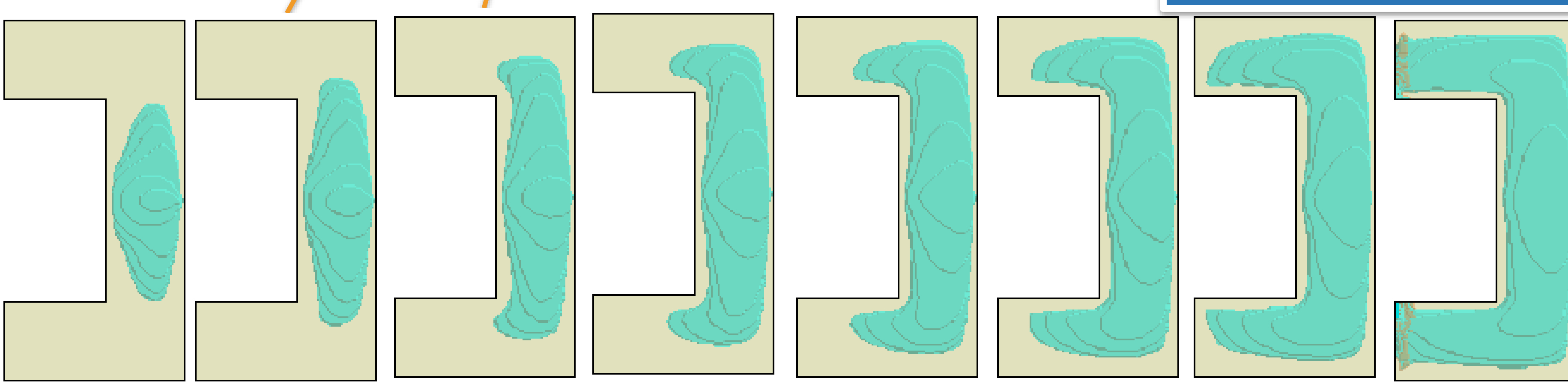
Core ratio (%)	10	15	20	25	30	35	40	50	60
S_0-S_1	1.56	1.6	1.44	1.3	1.2	1.12	1.1	1.12	0.98
S_0-S_2	1.05	1.03	0.92	0.86	0.83	0.79	0.79	0.75	0.69
S_2-S_1	0.51	0.57	0.52	0.44	0.37	0.33	0.31	0.37	0.29

Single shot (in the same condition with 1st shot)





When the core ratio is low, the warpage is similar to single shot. When core ratio reaches to 20%, the warpage of the two arms starts to decrease. Similar to above results, the effect decreases with the core ratio increases



Core Ratio 10% 15% 20% 25% 30% 35% 40% 50%

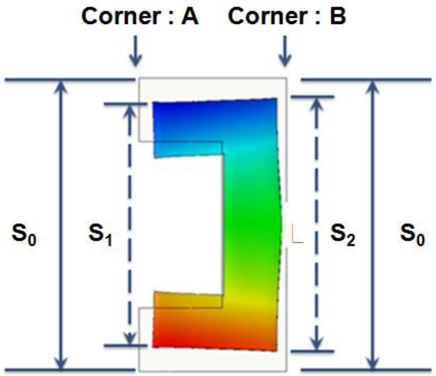
Flow rate effect 2

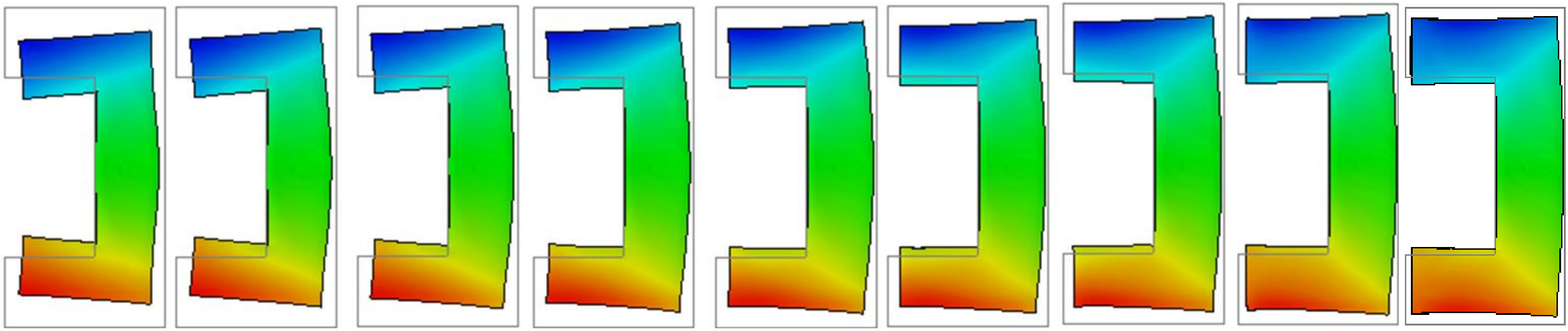
	Shot	Material	Flow rate	Melt temp.
Flow rate 2	1st	PC	20 cc/sec	305℃
	2nd	PC	20 cc/sec	305℃

Moldex3D

PC/PC Material:
High Melt Temp: 305^{o}C and 20/20 cc/sec

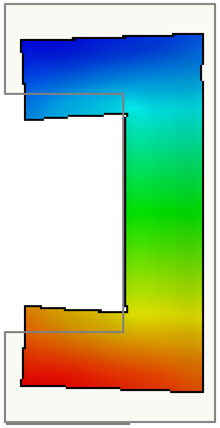
- S_0-S_1 means the warpage at corner A
- S_0-S_2 means the warpage at corner B
- And S_2-S_1 indicates the warpage trend of two arms is inward.



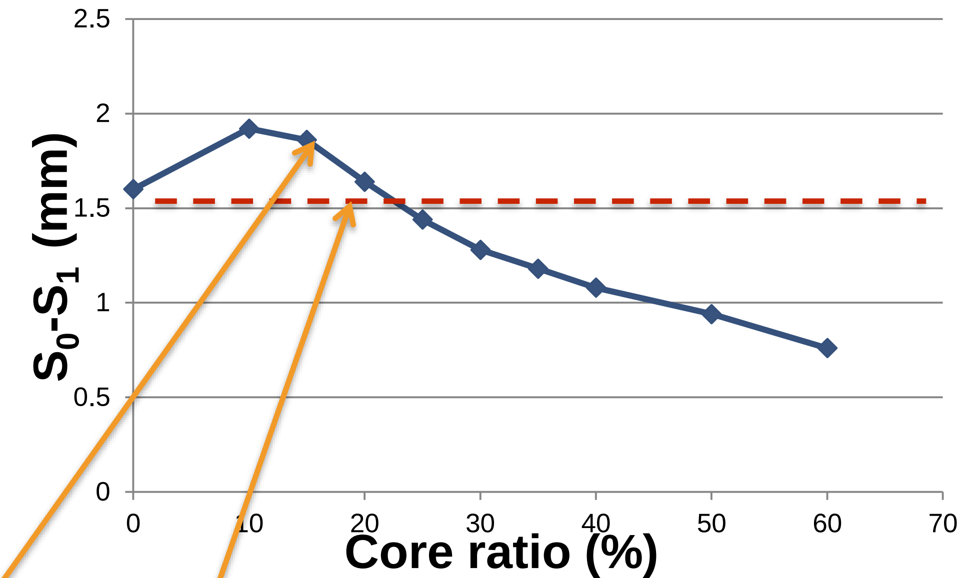


Core ratio (%)	10	15	20	25	30	35	40	50	60
S_0-S_1	1.92	1.86	1.64	1.44	1.28	1.18	1.08	0.94	0.76
S_0-S_2	1.34	1.18	1.01	0.89	0.82	0.76	0.7	0.55	0.47
S_2-S_1	0.58	0.68	0.63	0.55	0.46	0.42	0.38	0.39	0.29

Single shot (in the same condition with 1st shot)

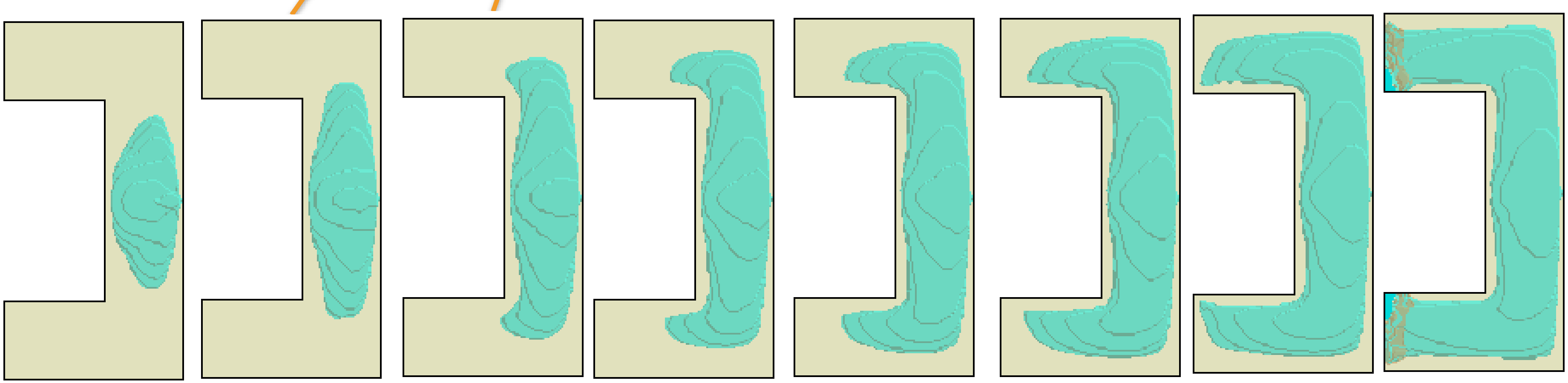


-0.8~0.8



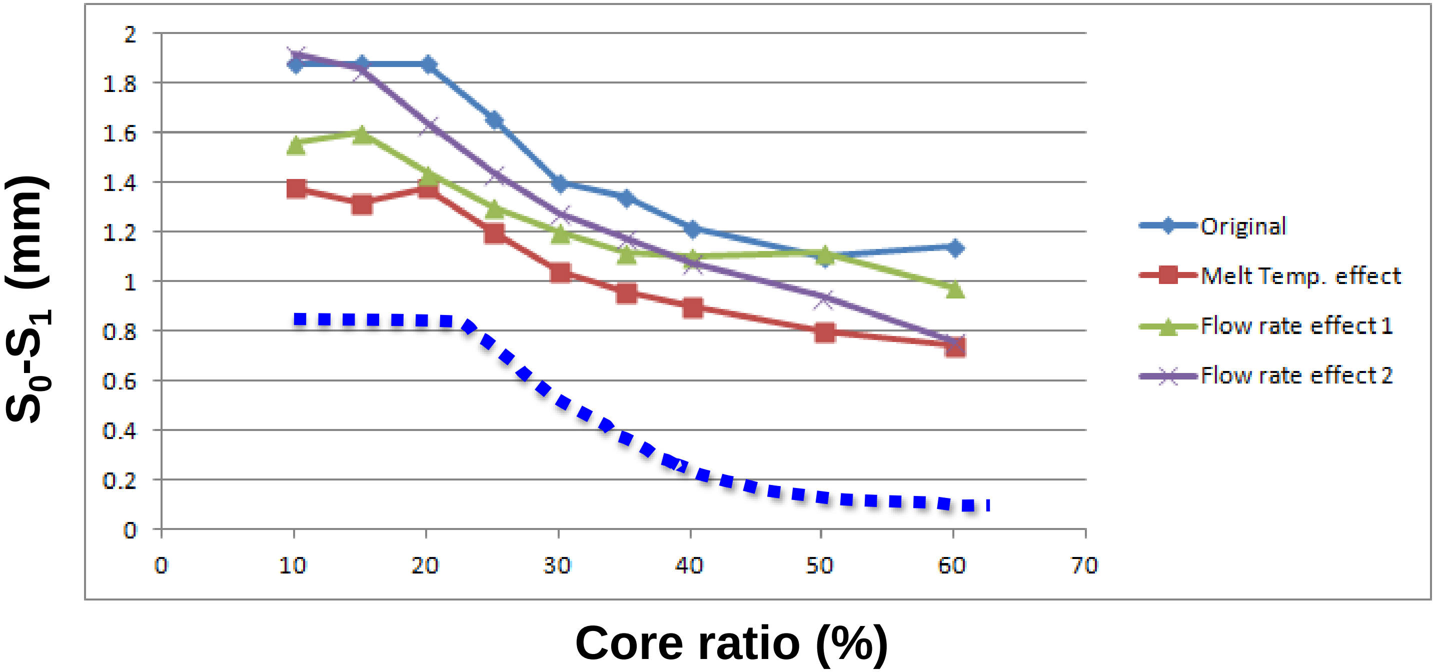
Comparing to single shot, warpage starts to decrease when the core ratio reaching to 20%.

Different from above results, the effect increases with the core ratio increases



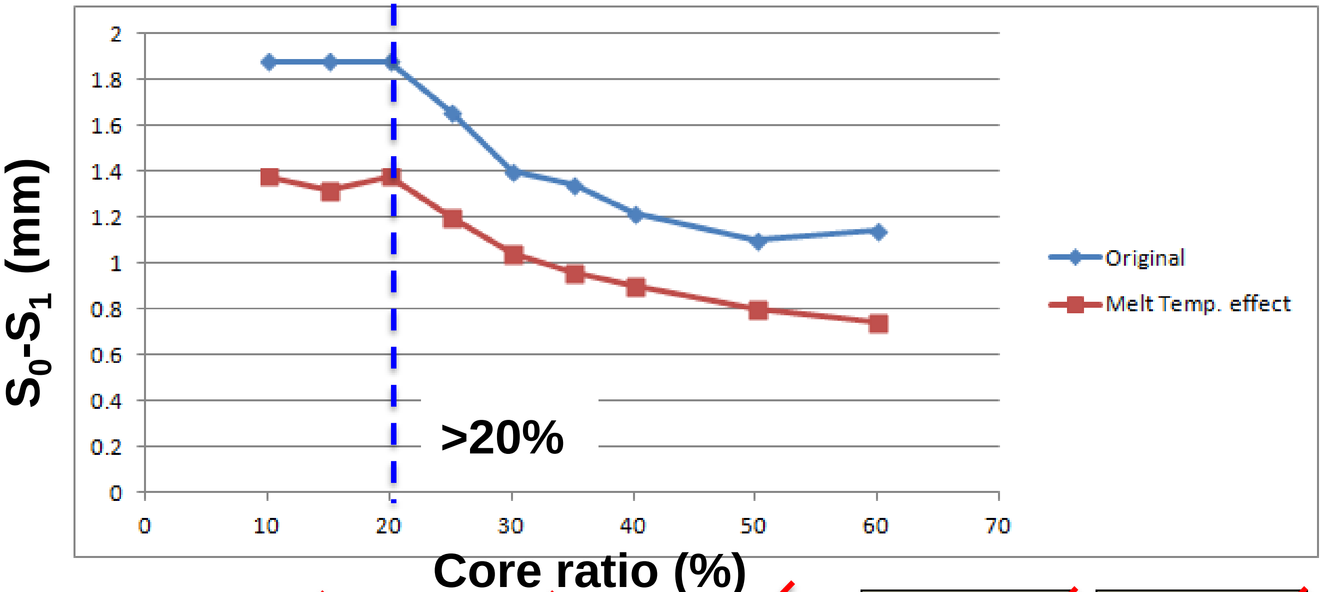
Core Ratio 10% 15% 20% 25% 30% 35% 40% 50%

Data Analysis

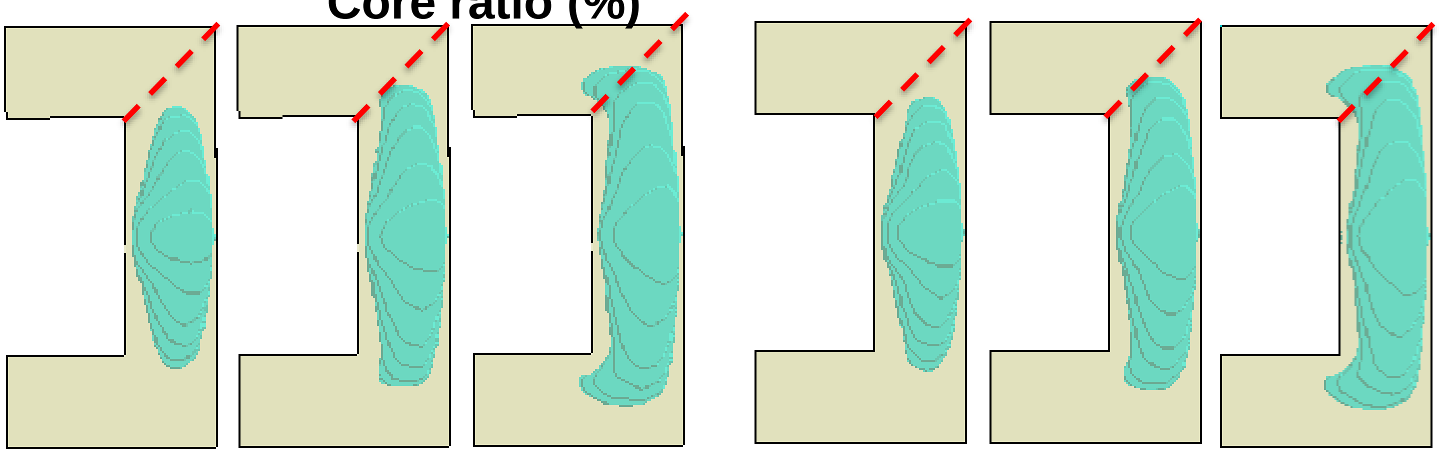


- > **The results indicate:**
- > **(1) With the increase of core ratio, warpage is improved.**
- > **(2) Except for “flow rate effect 2”, the improving rate of warpage decades with core ratio.**
- > **(3) The warpage is smallest with low melt temperature and can be improved most effectively by decreasing injection speed.**
- > **(4) The warpage can be improved more than 50% by adjusting core ratio and other processing condtions.**

Why can Co-injection improve warpage?

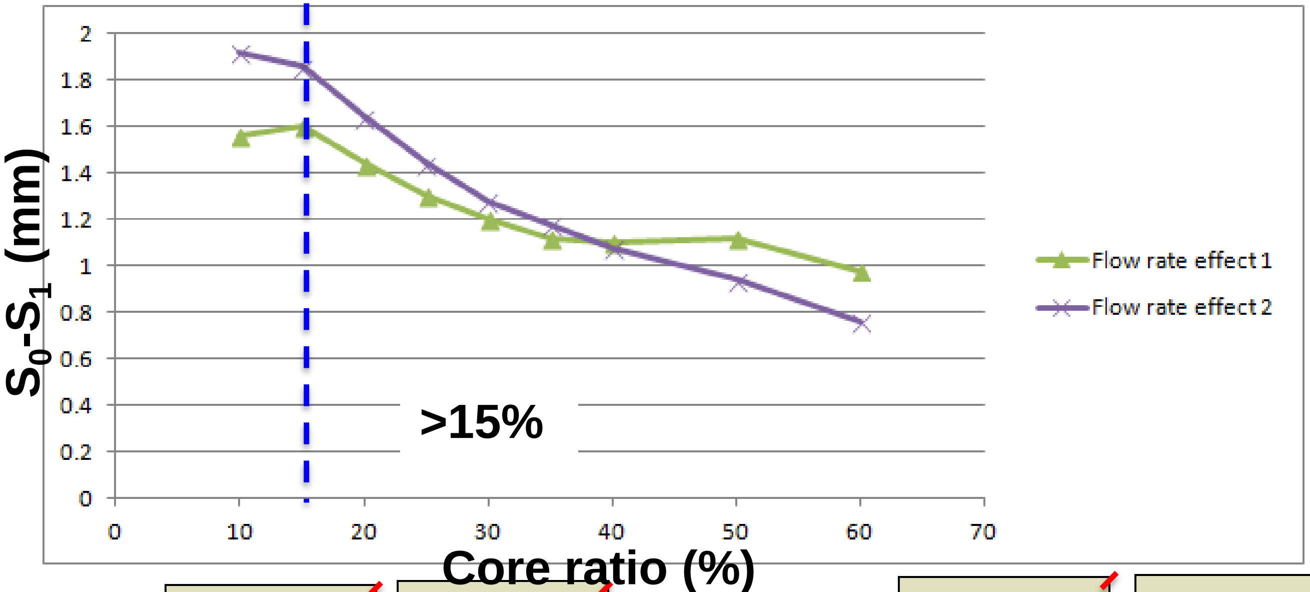


As core ratio is larger than 20%, the warp result is improved. From the two melt front results, when the core layer passes through the corner (diagonal line), the warp result is affected.



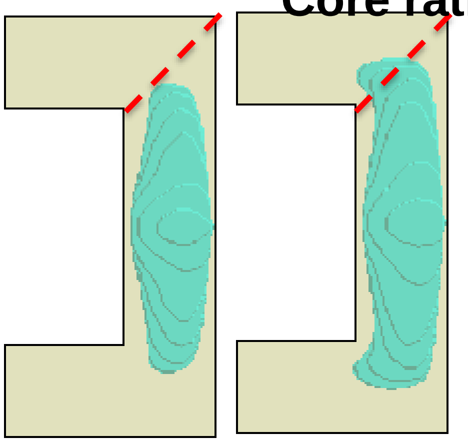
15% 20% 25% 15% 20% 25%

Original **Melt Temp effect**



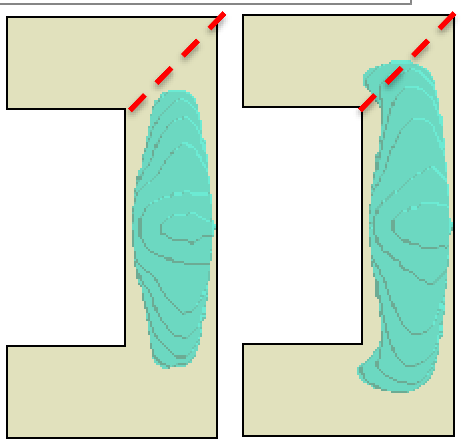
As core ratio is larger than 15%, the warp result is improved.

Similar to above results, when the core layer passes through the corner (diagonal line), the warp result is affected.



15% 20%

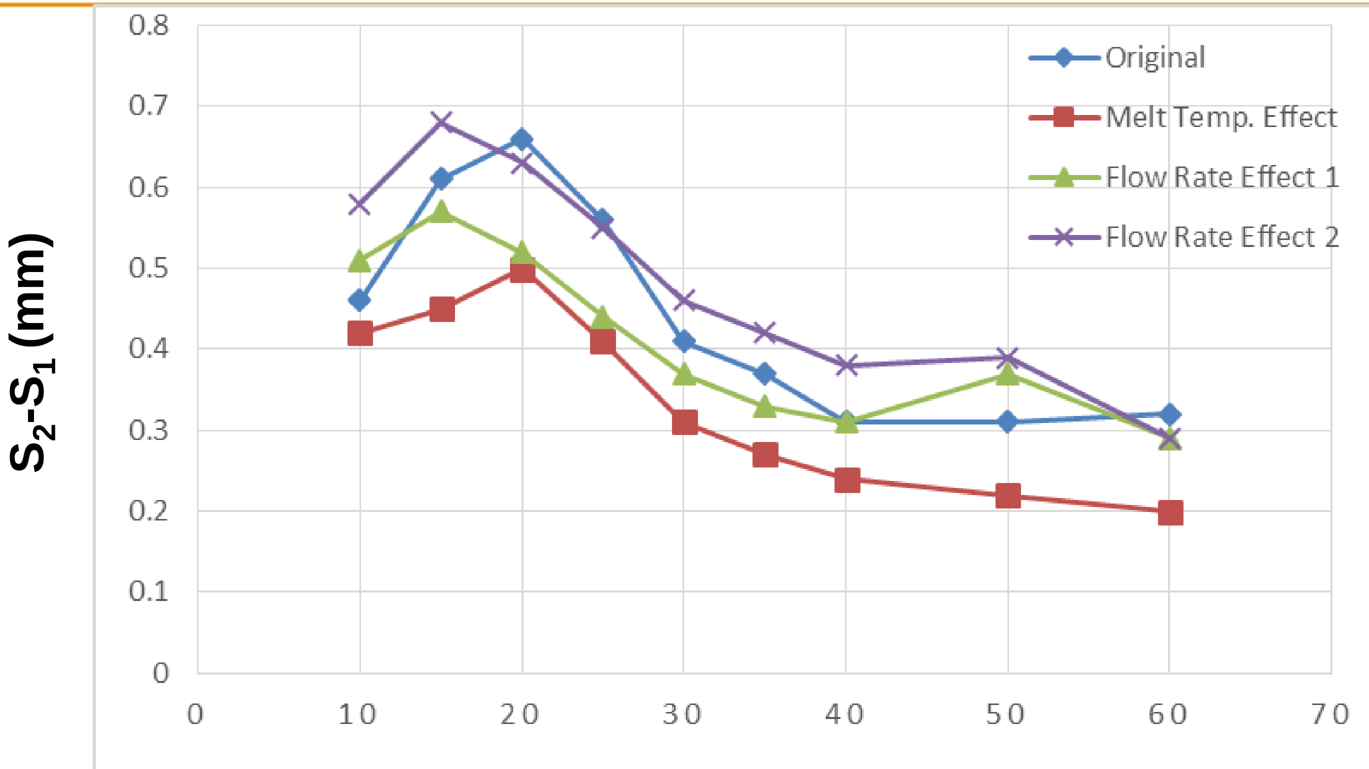
Flow rate effect 1



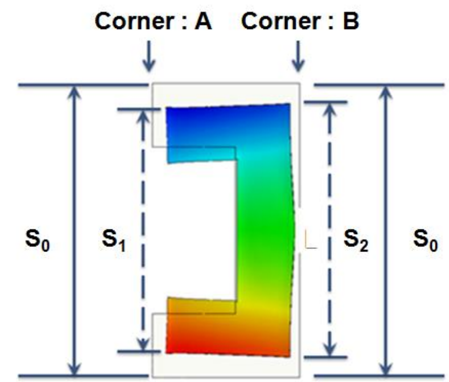
15% 20%

Flow rate effect 2

S2-S1



Core ratio (%)



Similar results can be observed on S_2-S_1 diagram.
When core penetrates through the diagonal line, the S_2-S_1 value becomes smaller, which means S_1 is approaching S_2.

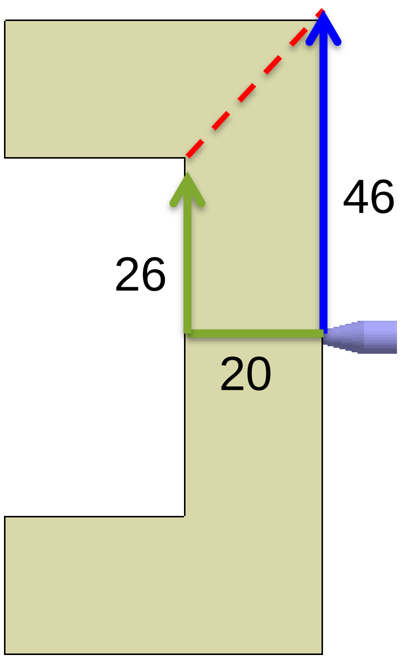
In other words, when the core penetrates through the diagonal, the displacements of A and B reduces and become close to each other.

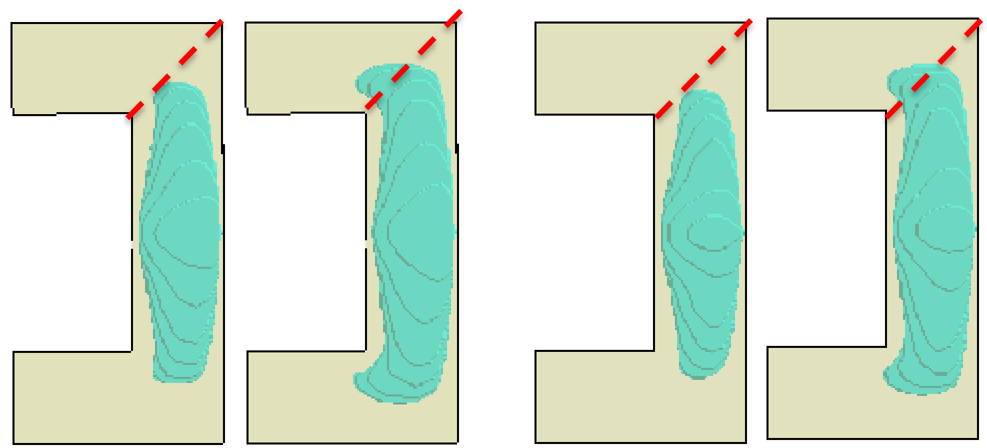
Critical Penetration Distance

> According to present analysis results, as core across the diagonal line, the warpage has been controlled and Improved ,the distance from gate to diagonal line we call "**critical penetration distance**."

> In this case, critical penetration distance is 46 mm.

> It means when core penetration distance is above 46mm, the warpage will be improved.





20% 25%

Original

15% 20%

Flow rate effect 1

Remarks for PC/PC

In this study for warpage mechanism of co-injection

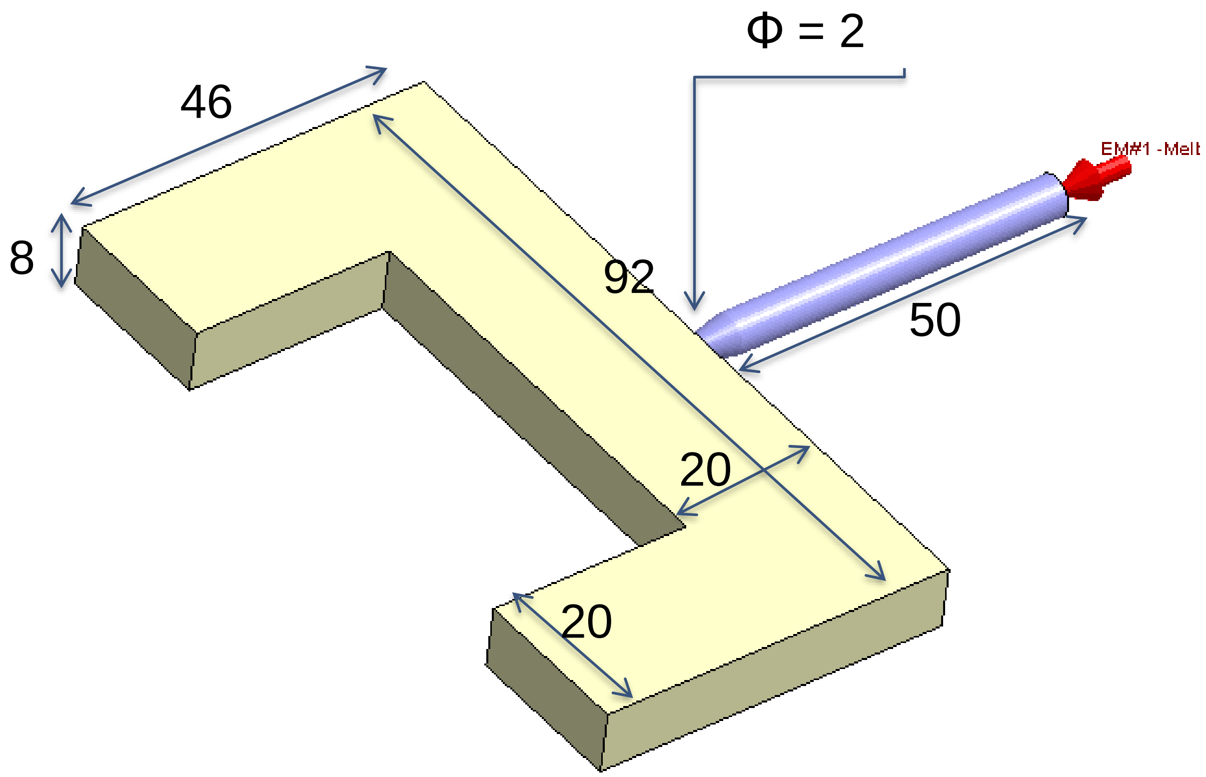
> In PC/PC co-injection (amorphous) system
  - Core ratio effect:
    - The higher core ratio, the better
  - Melt temperature effect:
    - The lower, the better
  - 1st shot effect:
    - The slower 1st shot, the better.

> When core penetration distance is above "critical penetration distance", the warpage will be improved.

II. PP

A Standard Part

> **Input Mesh**

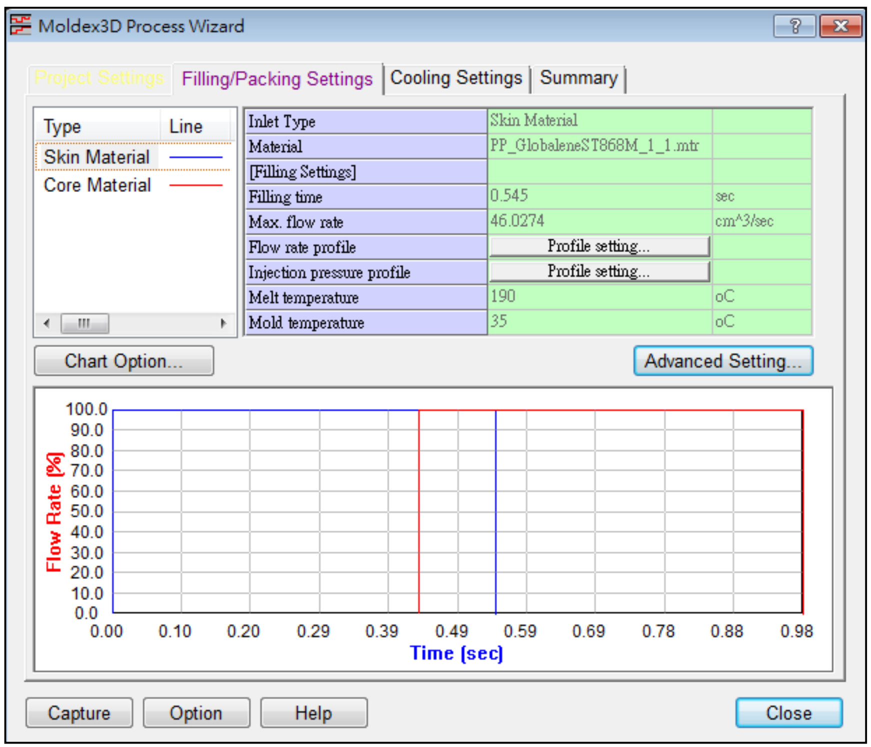


Unit: mm
Part Volume: 23,040 mm^3

Moldex3D

Operating Condition

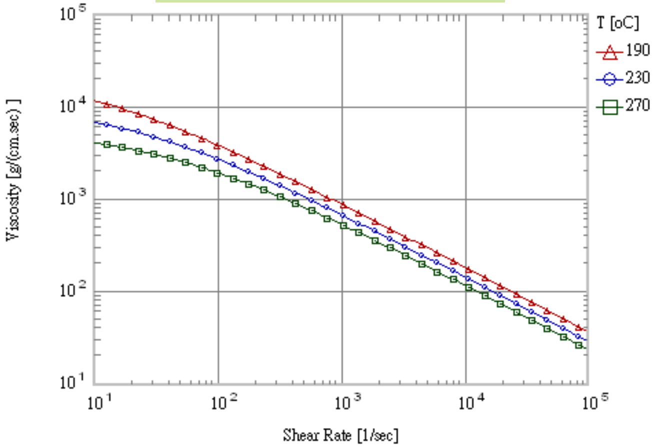
- > Melt Temperature: 190 ^{o}C
- > Mold Temperature: 35 ^{o}C
- > Filling Time = 0.545 sec



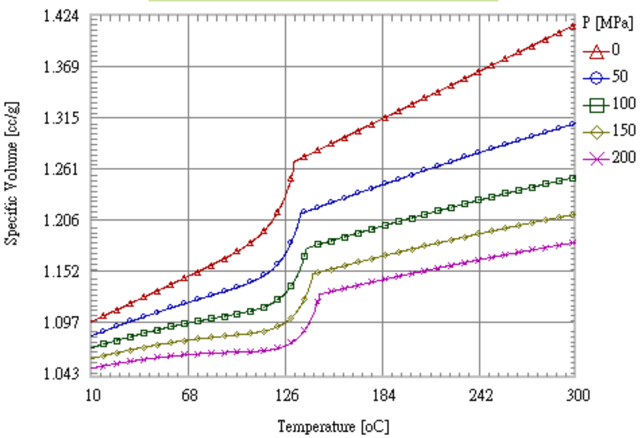
[Filling]	
Filling time (sec)	0.545
Melt Temperature (oC)	190
Mold Temperature (oC)	35
Maximum injection pressure (MPa)	250
Injection volume (cm^3)	25.0849
[Packing]	
Packing Time (sec)	5
Maximum packing pressure (MPa)	250
[Cooling]	
Cooling Time (sec)	50
Mold-Open Time (sec)	5
Eject Temperature (oC)	101.35
Air Temperature (oC)	25
[Miscellaneous]	
Cycle time (sec)	60.545
Mesh file	pin gate.mfe
Material file	PP_GlobaleneST868M_1_1.mtrPP...

Material Properties

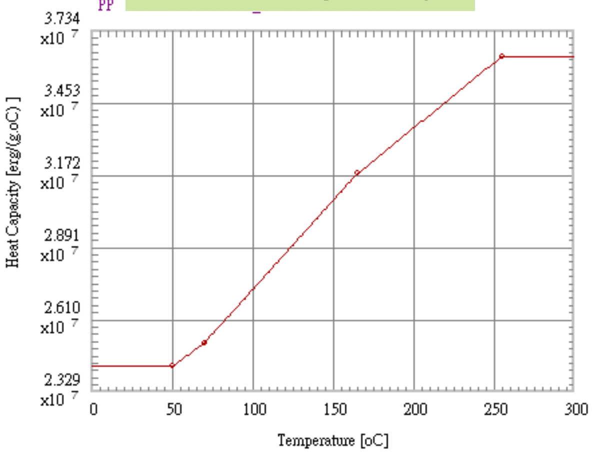
Viscosity



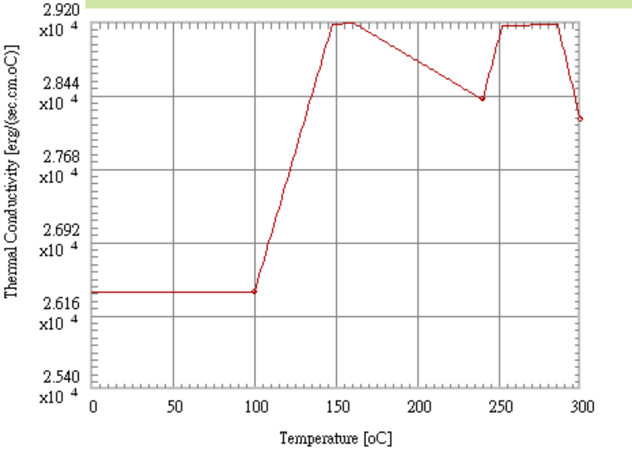
PVT



Heat capacity

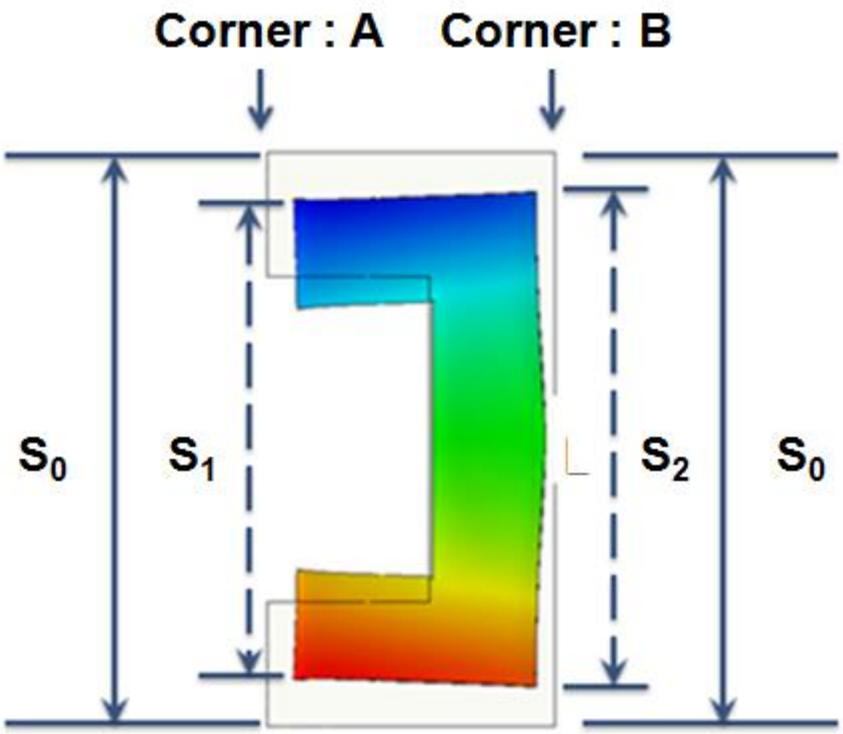


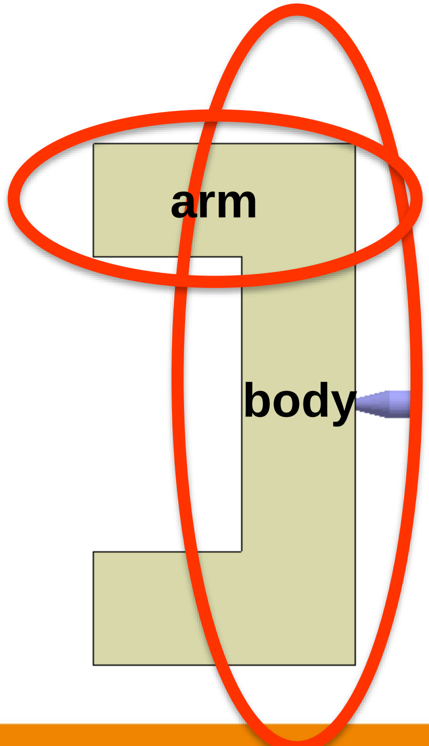
Thermal conductivity



Definition for Warpage Behavior

> Warpage behavior definition for Inward or Outward:
  - at Corner A, when $S_1<S_0$, it is inward, where S_0 is the original design length;
  - at Corner B, when $S_2<S_0$, it is Inward.
  - As S2>S1, it is inward for two arms.





Moldex3D

Process Conditions

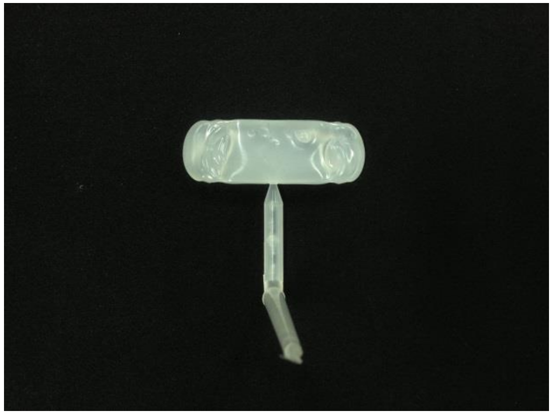
	Shot	Material	Flow rate	Melt temp.
Original	1st	PP	46 cc/sec	190℃
	2nd	PP	46 cc/sec	190℃
Melt temp.	1st	PP	46 cc/sec	210℃
	2nd	PP	46 cc/sec	210℃
Melt temp. 2	1st	PP	46 cc/sec	230℃
	2nd	PP	46 cc/sec	230℃
Flow rate	1st	PP	23 cc/sec	190℃
	2nd	PP	46 cc/sec	190℃
Flow rate 2	1st	PP	23 cc/sec	190℃
	2nd	PP	23 cc/sec	190℃

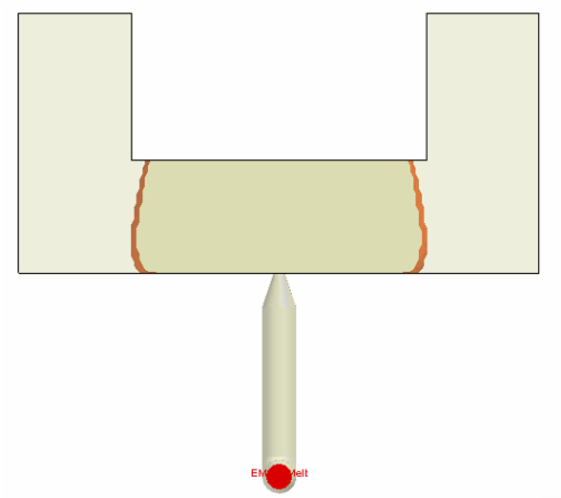
A. Filling Behavior

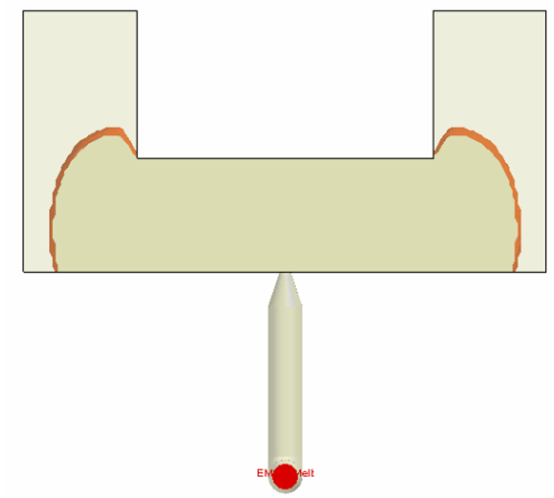
Short shots with various core ratio
Original Test

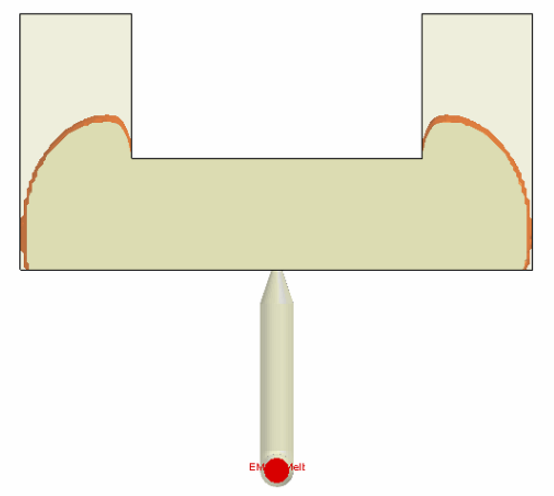
	Shot	Material	Flow rate	Melt temp.
Original	1st	PP	46 cc/sec	190℃
	2nd	PP	46 cc/sec	190℃

Core ratio = 20%



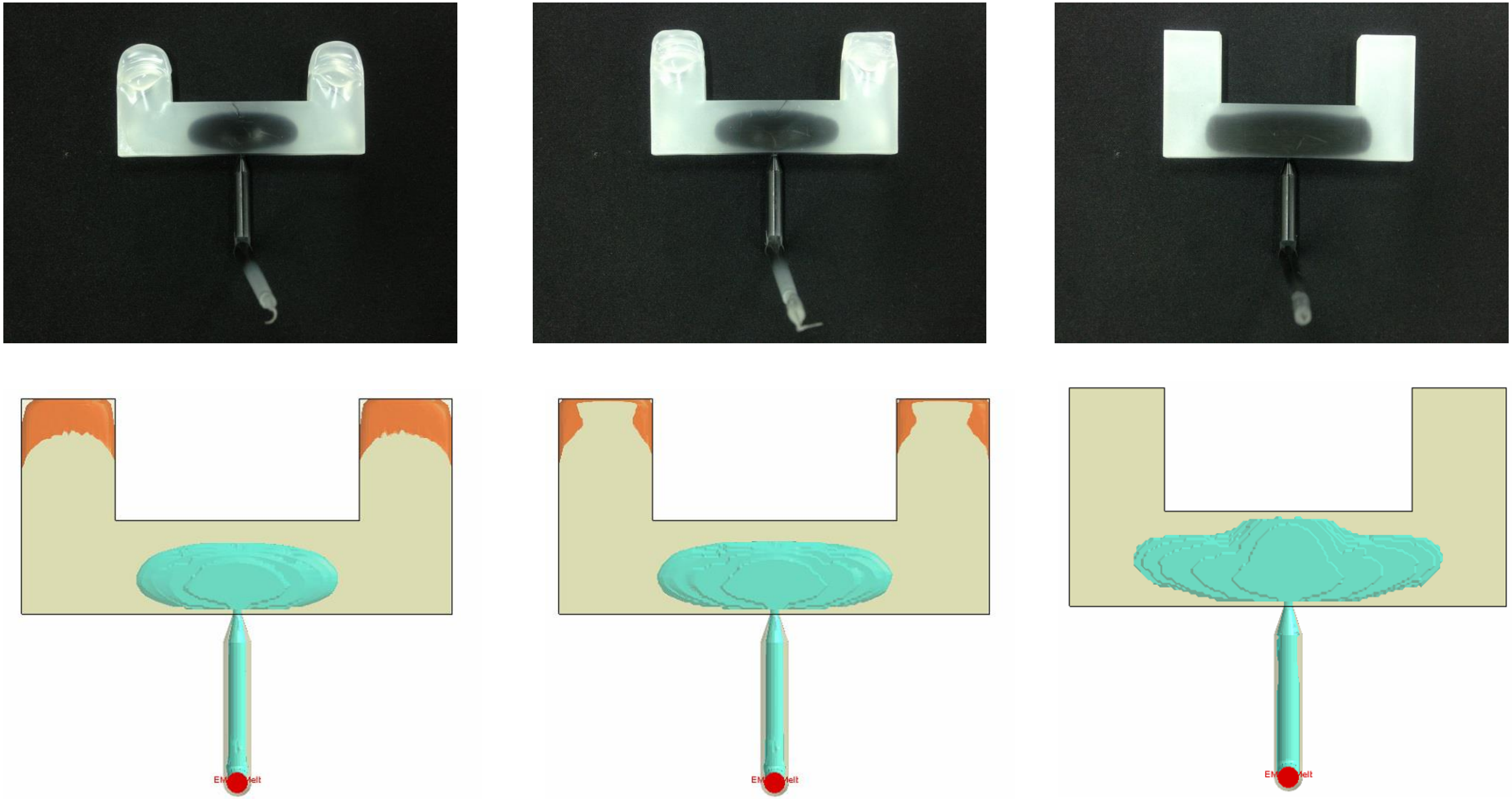






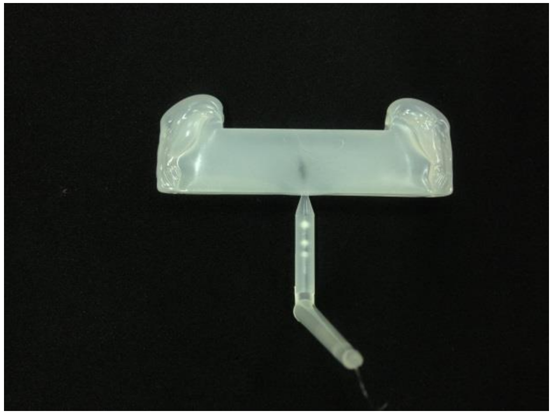
Short shot 38% 62% 71%

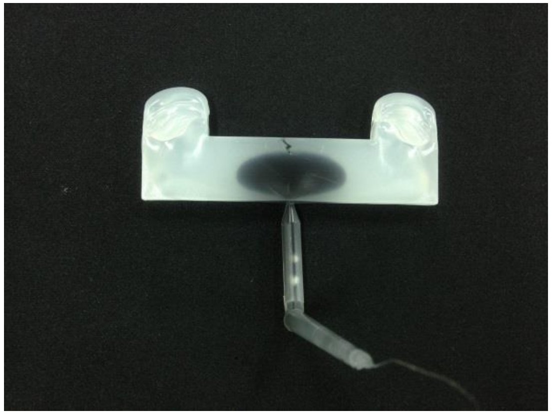
Core ratio = 20%

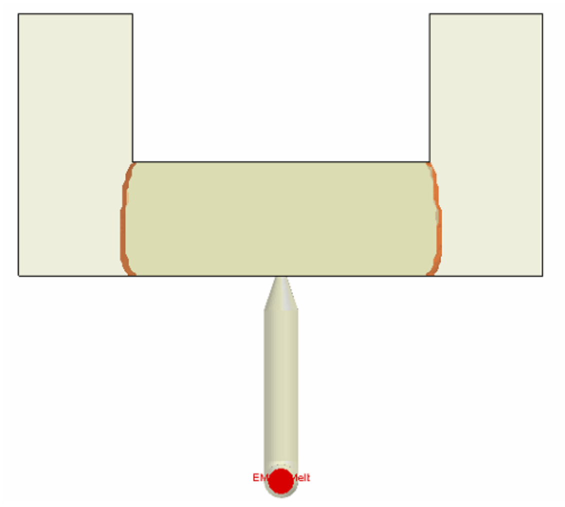


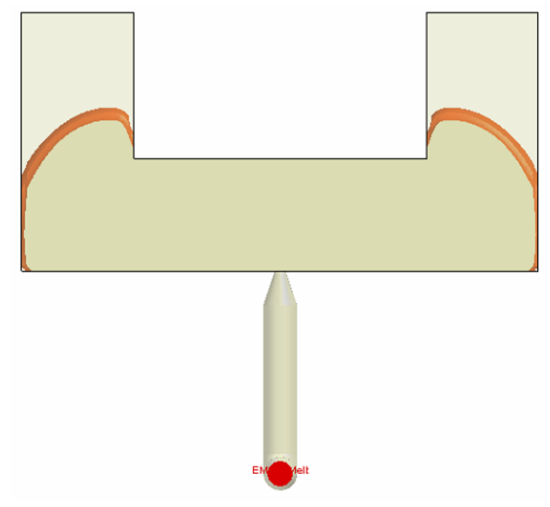
Short shot 98% 99% 100%

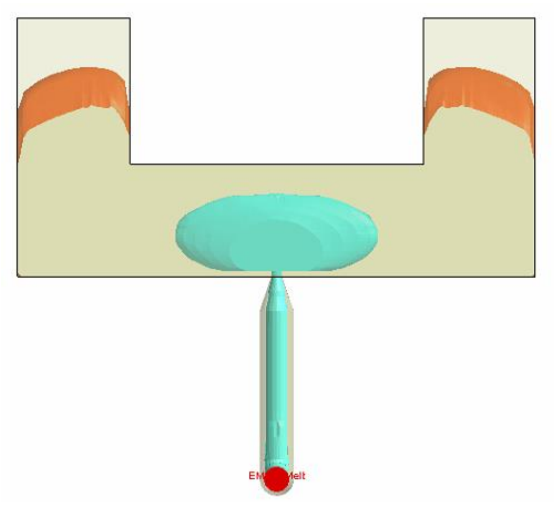
Core ratio = 30%





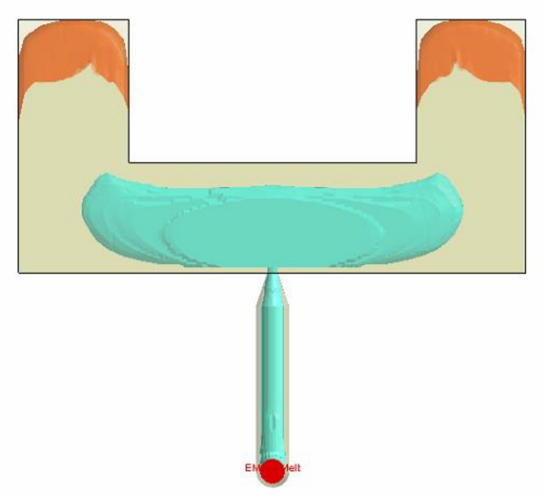


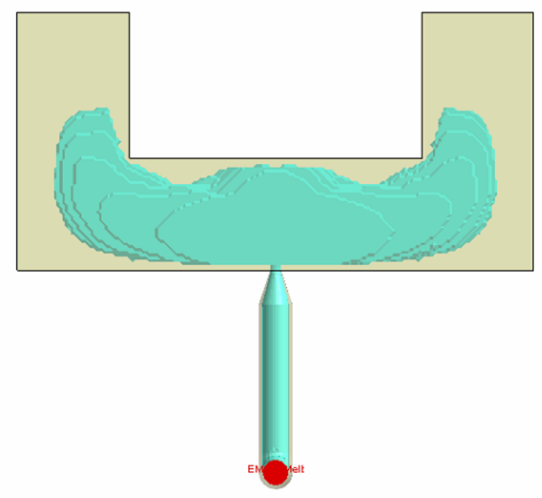




Short shot 42% 75% 87%

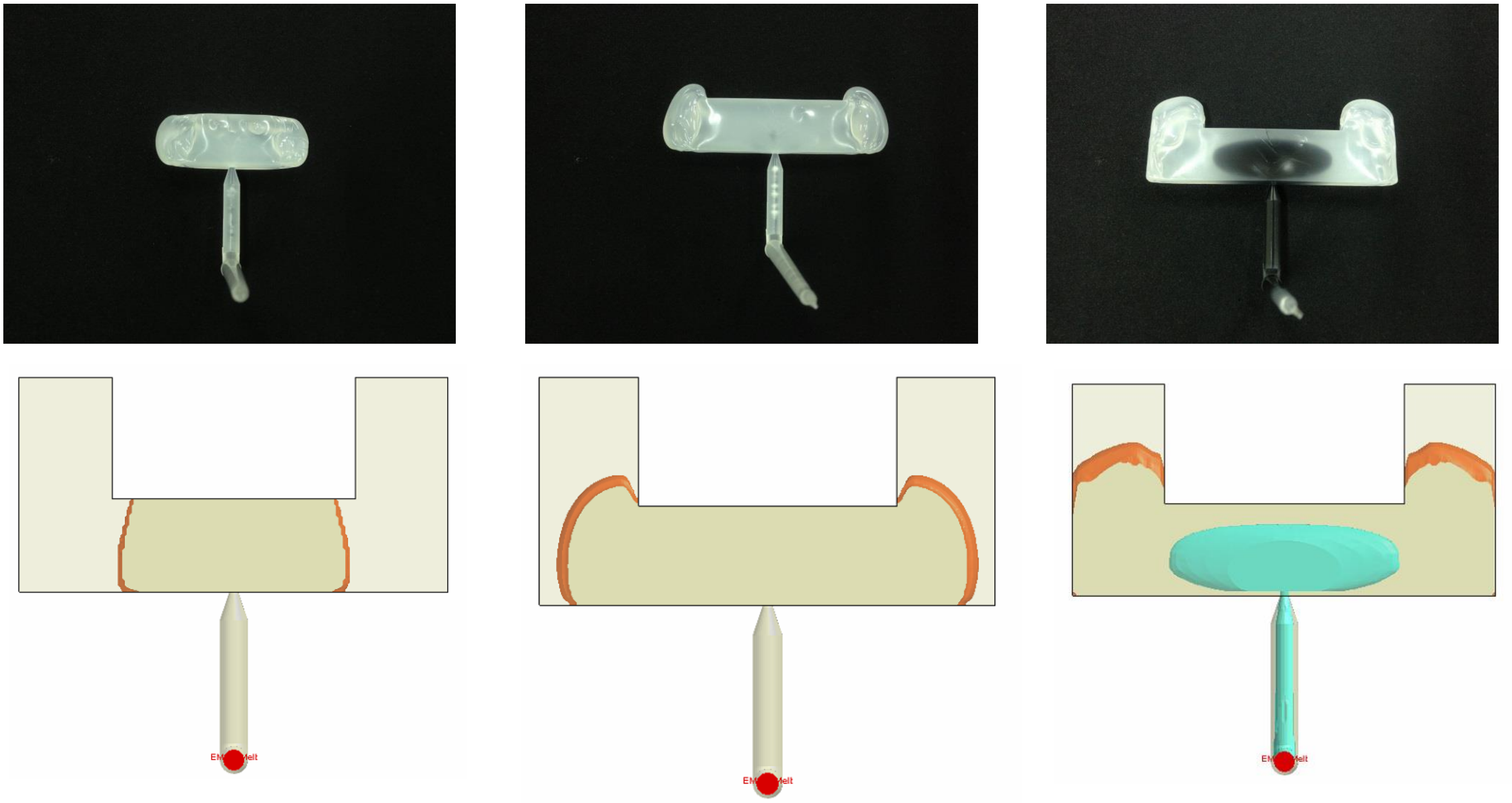
Core ratio = 30%





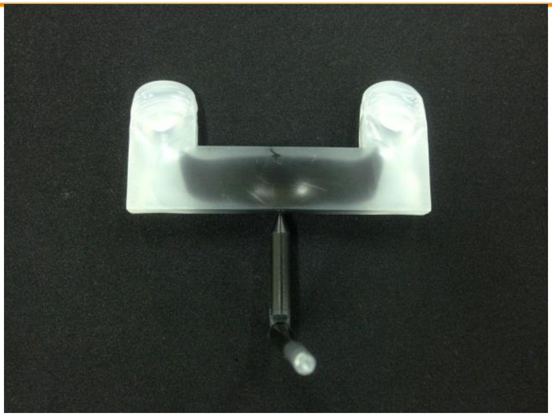
Short shot 98% 100%

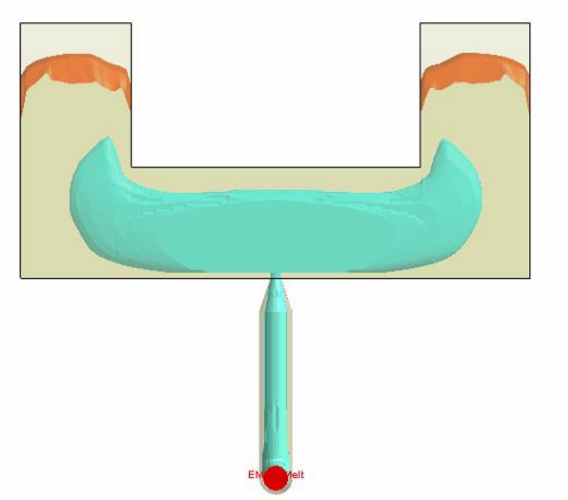
Core ratio = 40%

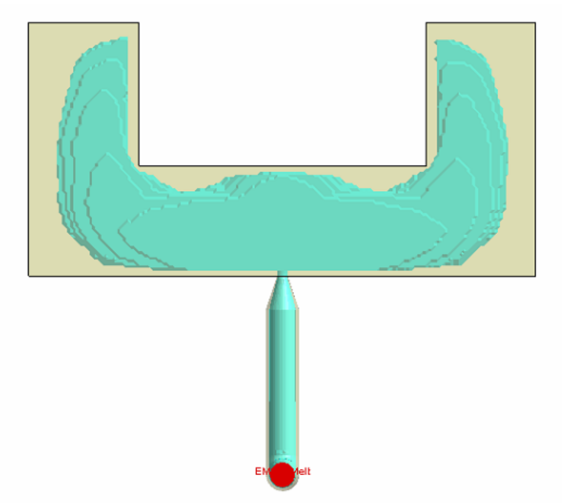


Short shot 38% 66% 81%

Core ratio = 40%





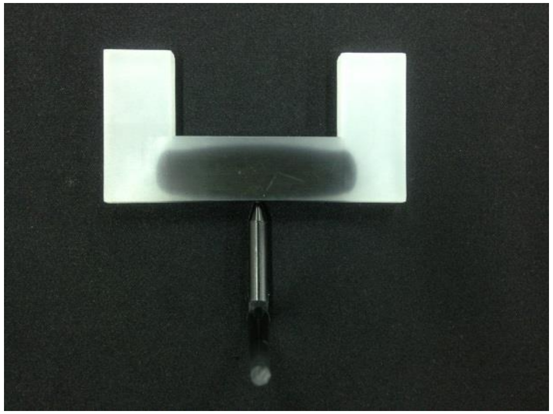
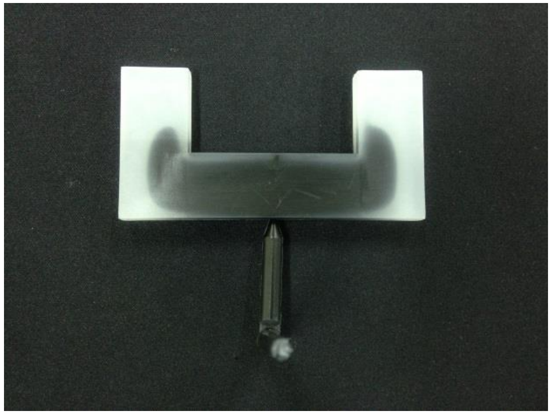


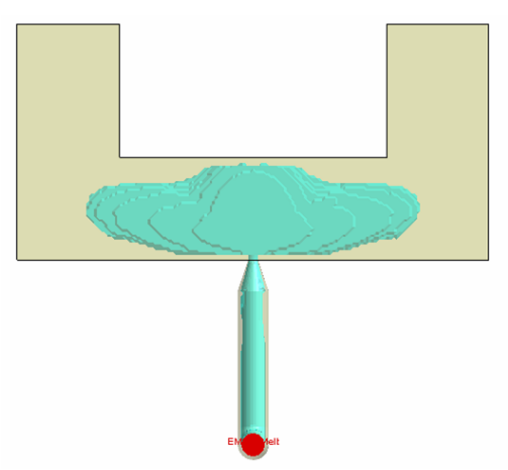
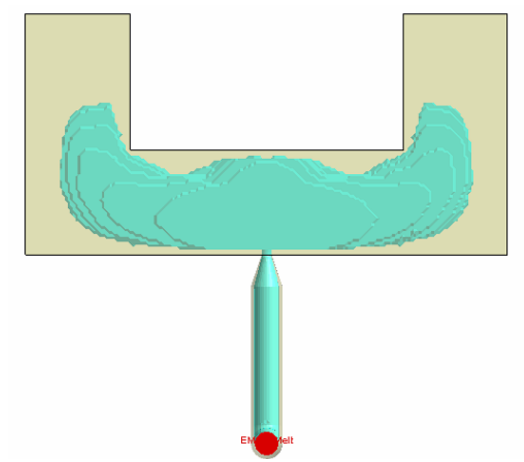
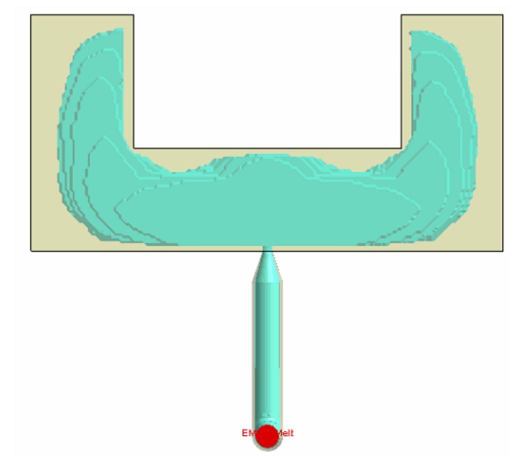
Short shot 92% 100%

Melt Front at End of Filling
Original Test

	Shot	Material	Flow rate	Melt temp.
Original	1^{st}	PP	46 cc/sec	190℃
	2^{nd}	PP	46 cc/sec	190℃

Moldex3D

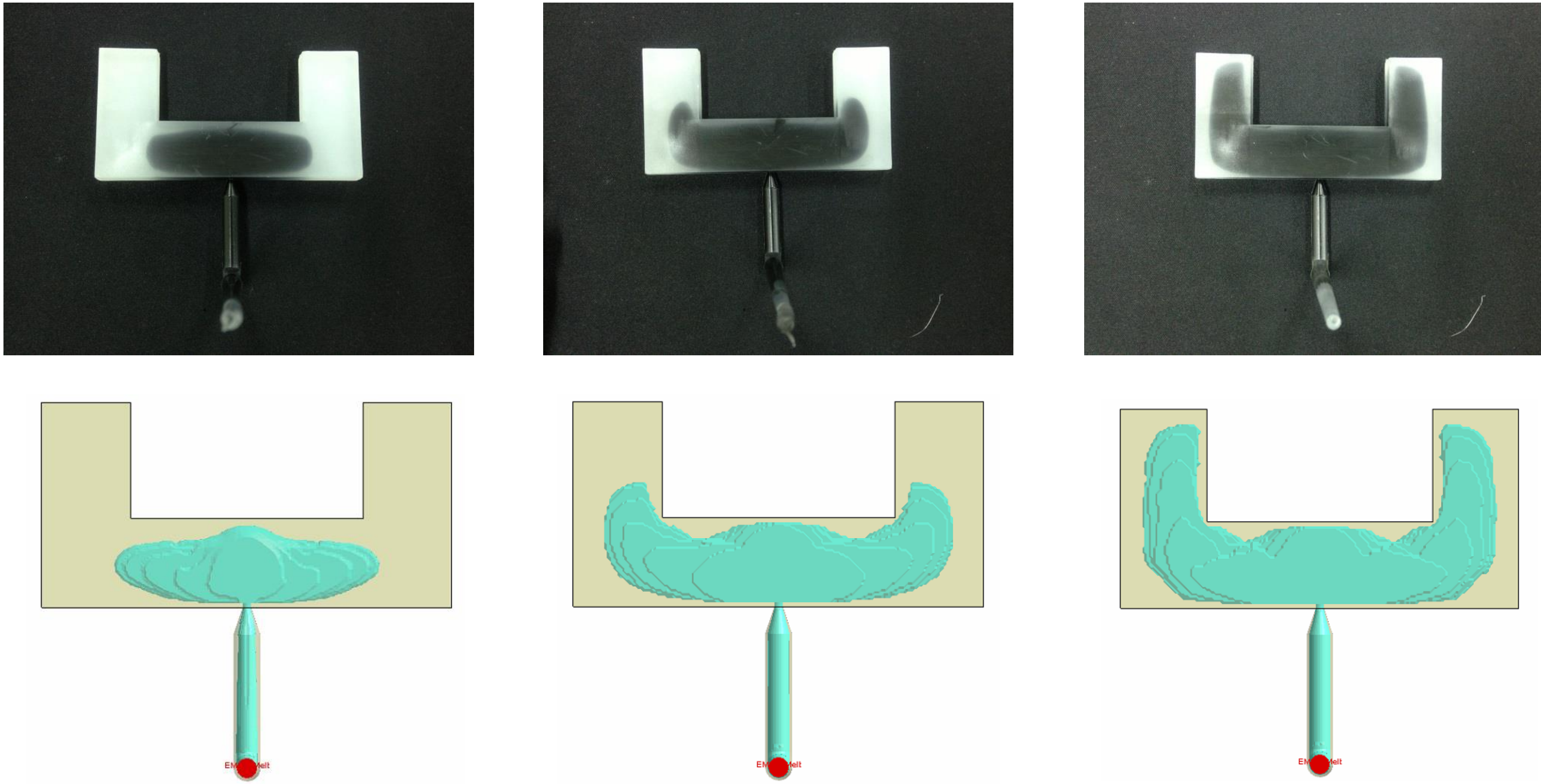



Core ratio 20% 30% 40%

Melt Front at End of Filling
Melt Temp. Effect

	Shot	Material	Flow rate	Melt temp.
Melt temp.	1st	PP	46 cc/sec	210℃
	2nd	PP	46 cc/sec	210℃

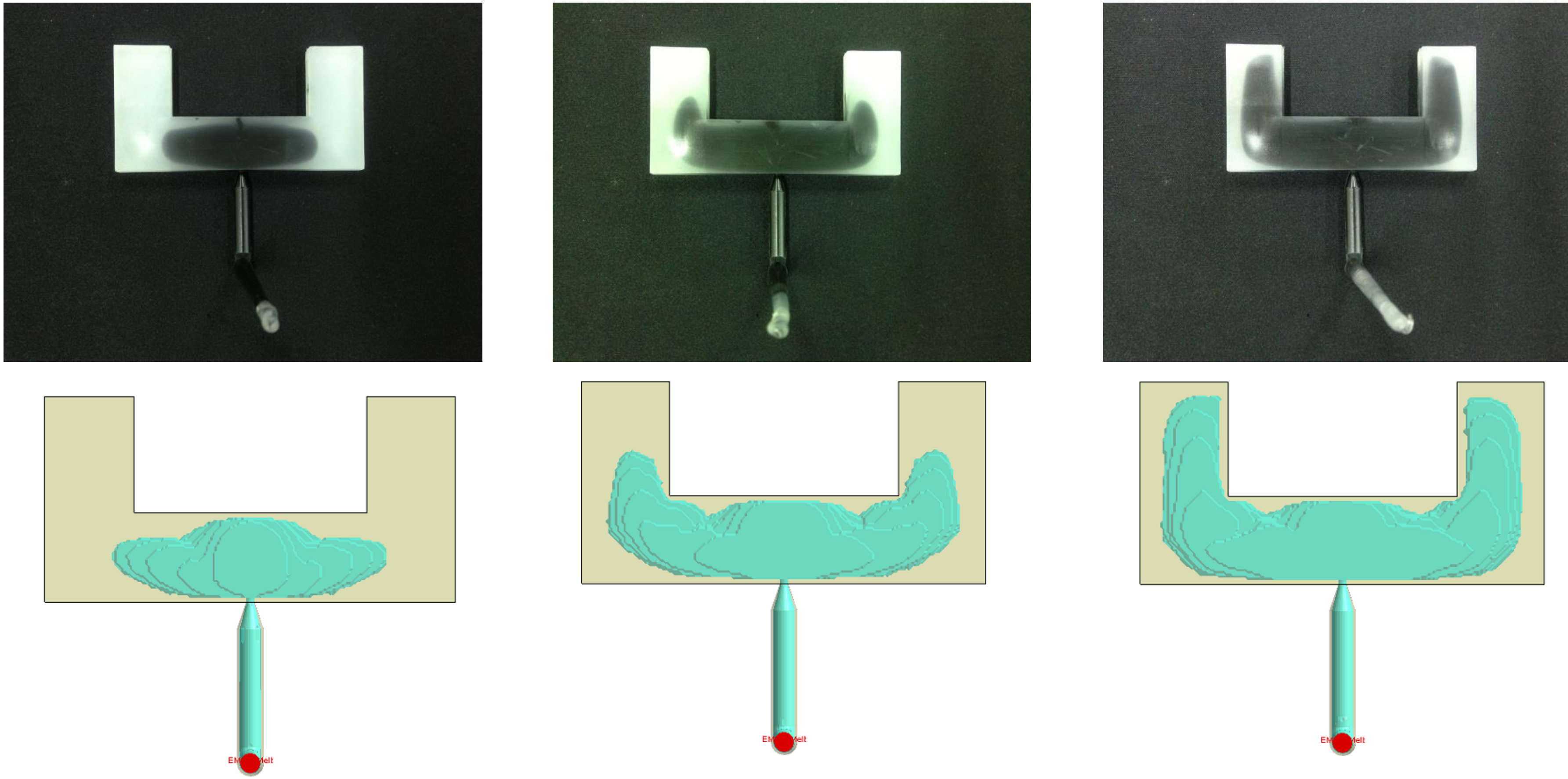


Core ratio 20% 30% 40%

Melt Front at End of Filling
Melt Temp. Effect 2

	Shot	Material	Flow rate	Melt temp.
Melt temp. 2	1st	PP	46 cc/sec	230℃
	2nd	PP	46 cc/sec	230℃

Moldex3D

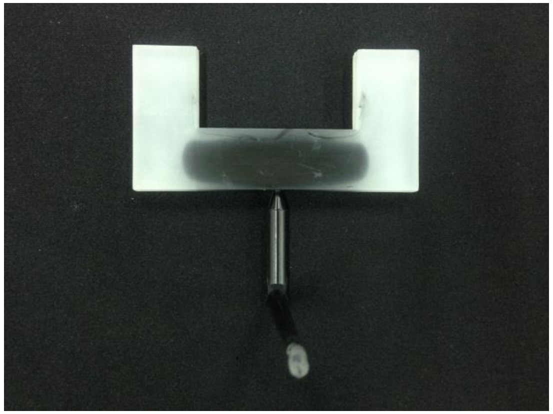
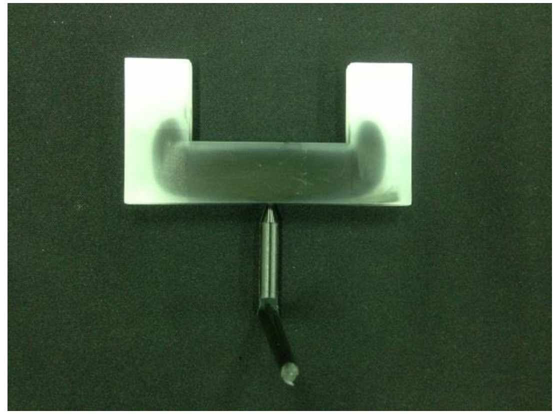
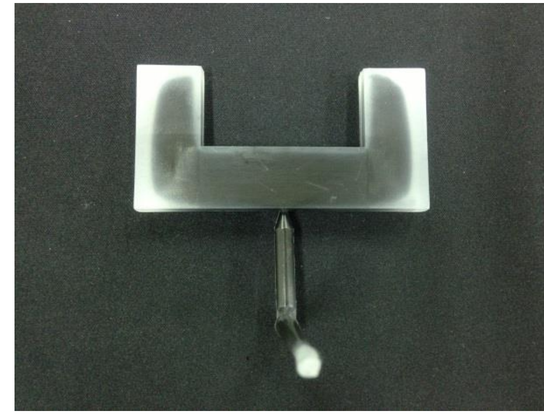
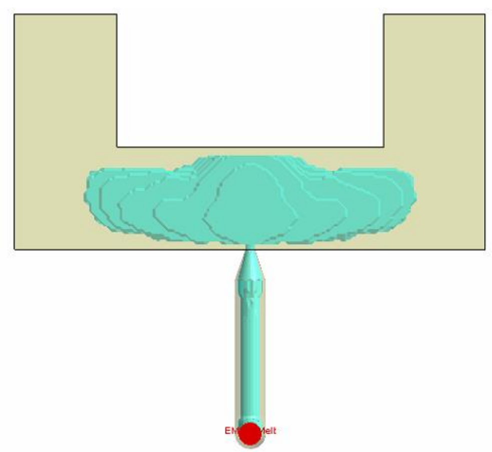
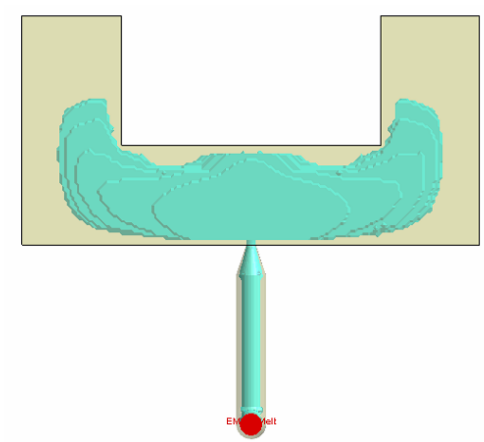
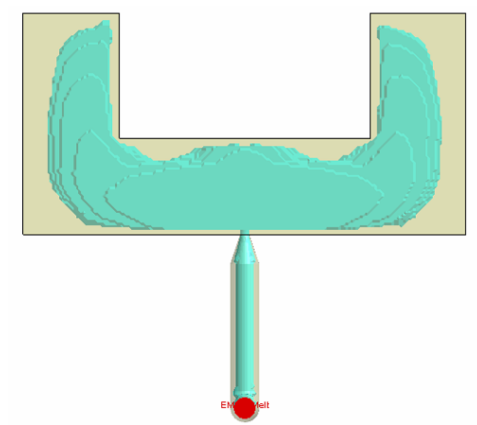


Core ratio 20% 30% 40%

Melt Front at End of Filling

Flow Rate Effect

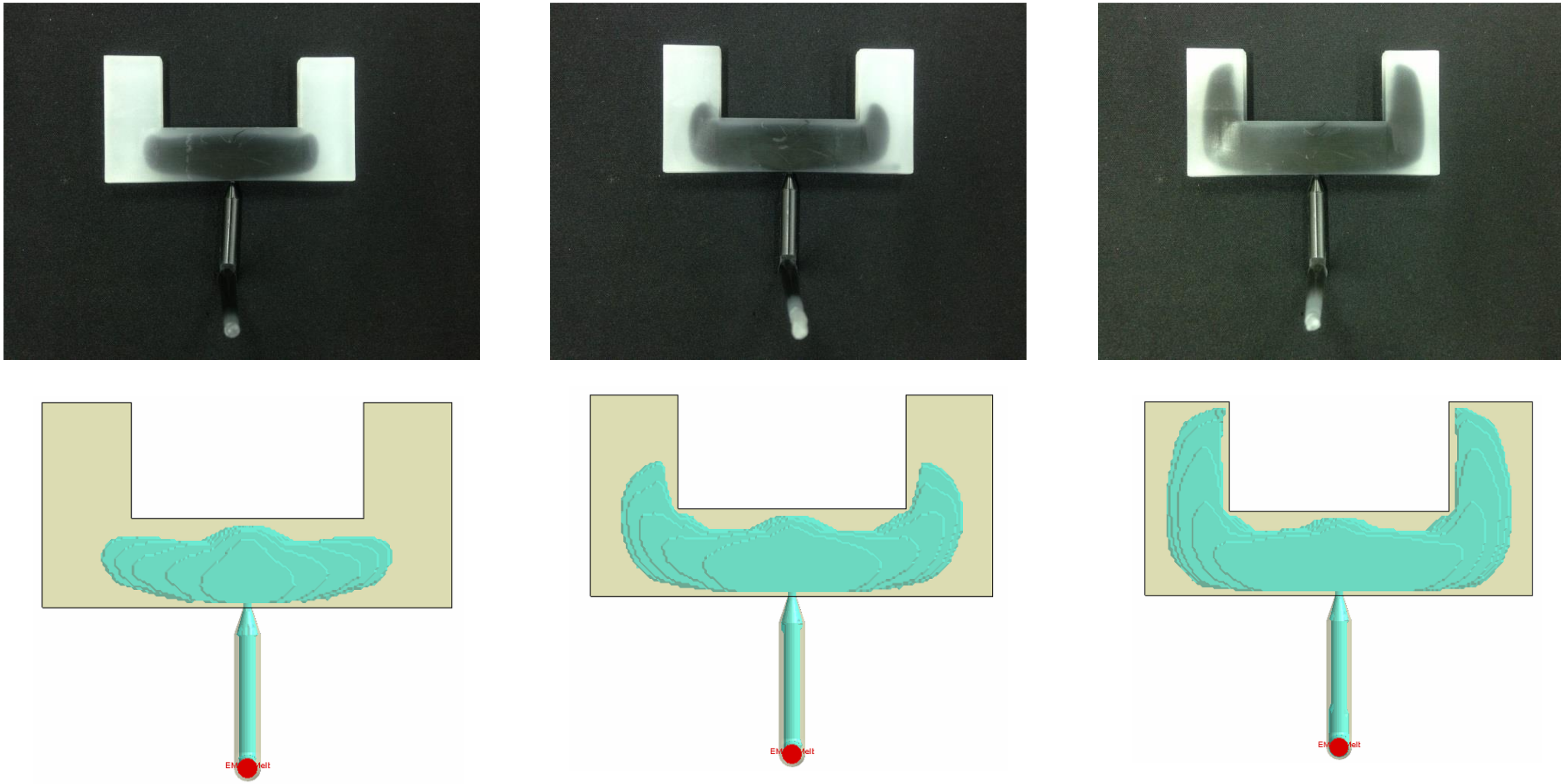
	Shot	Material	Flow rate	Melt temp.
Flow rate	1st	PP	23 cc/sec	190℃
	2nd	PP	46 cc/sec	190℃

Core ratio 20% 30% 40%

Melt Front at End of Filling
Flow Rate Effect 2

	Shot	Material	Flow rate	Melt temp.
Flow rate 2	1st	PP	23 cc/sec	190℃
	2nd	PP	23 cc/sec	190℃



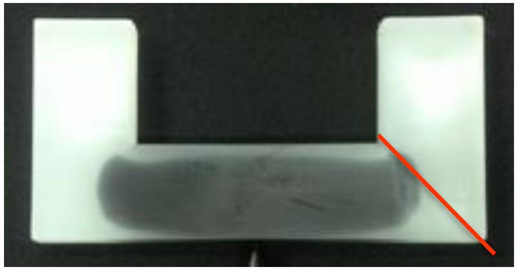
Core ratio 20% 30% 40%

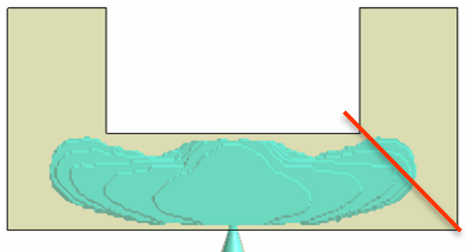
Result

> The melt behavior of simulation is very similar to real.

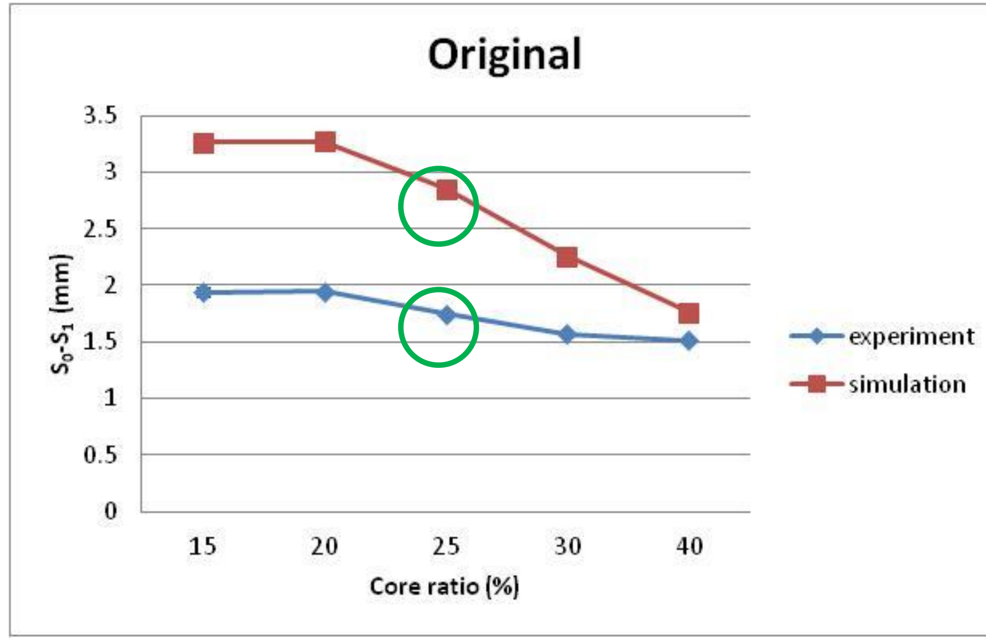
B. Warpage

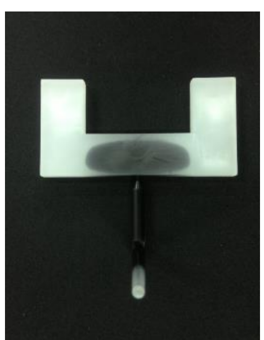
Original

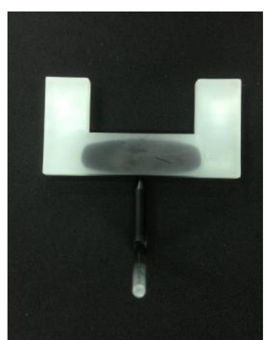




	Shot	Material	Flow rate	Melt temp.
Original	1st	PP	46 cc/sec	190℃
	2nd	PP	46 cc/sec	190℃

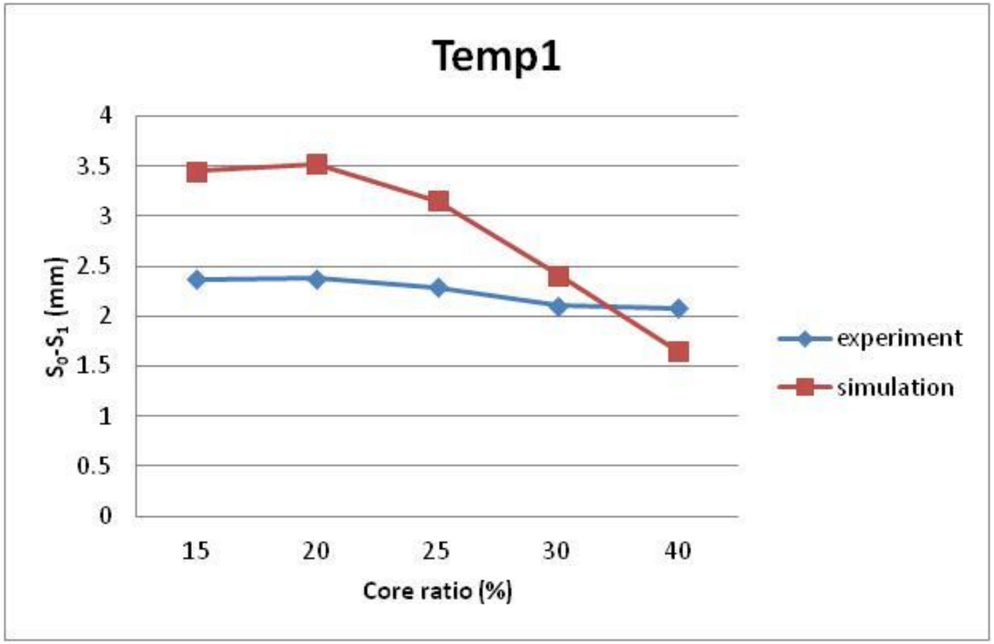




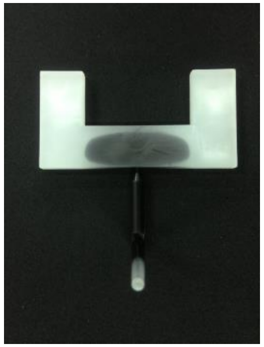


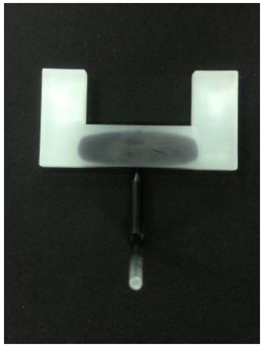
Core ratio(%) 15 20 25 30 40

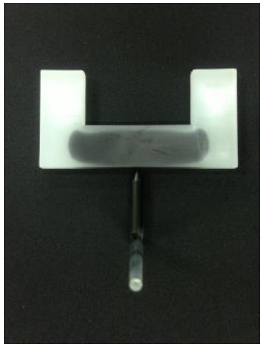
Temp 1

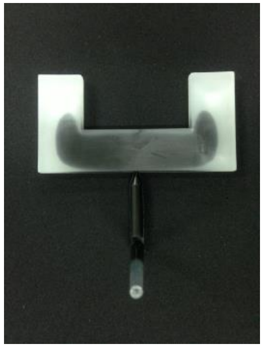


	Shot	Material	Flow rate	Melt temp.
Melt temp.	1st	PP	46 cc/sec	210℃
	2nd	PP	46 cc/sec	210℃



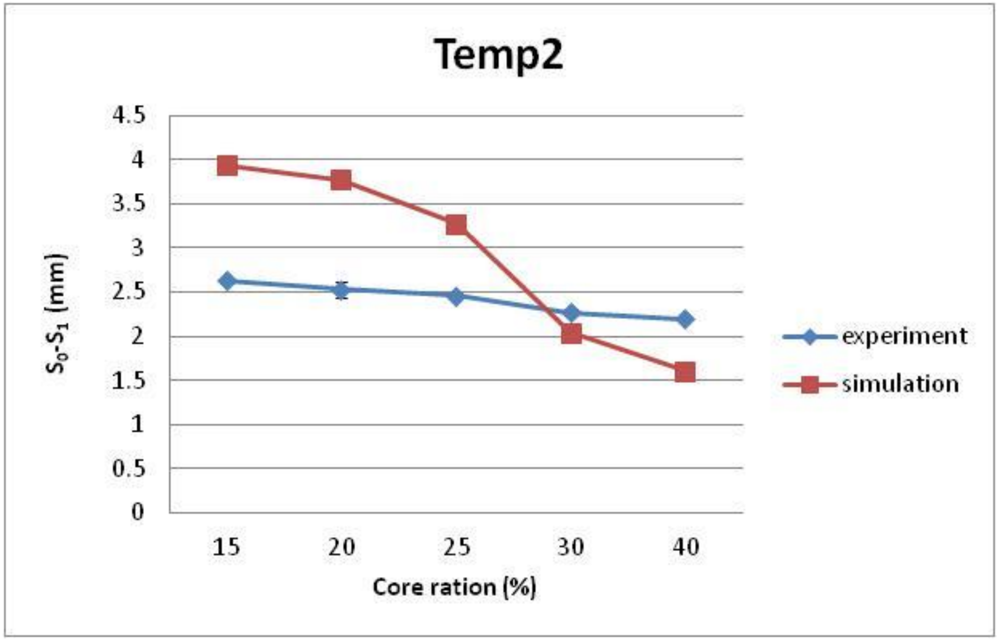




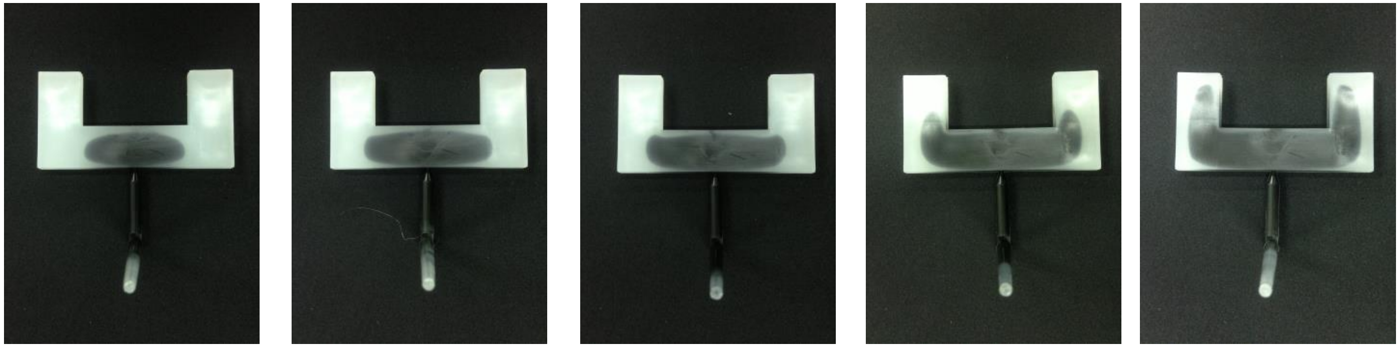


Core ratio(%) 15 20 25 30 40

Temp 2

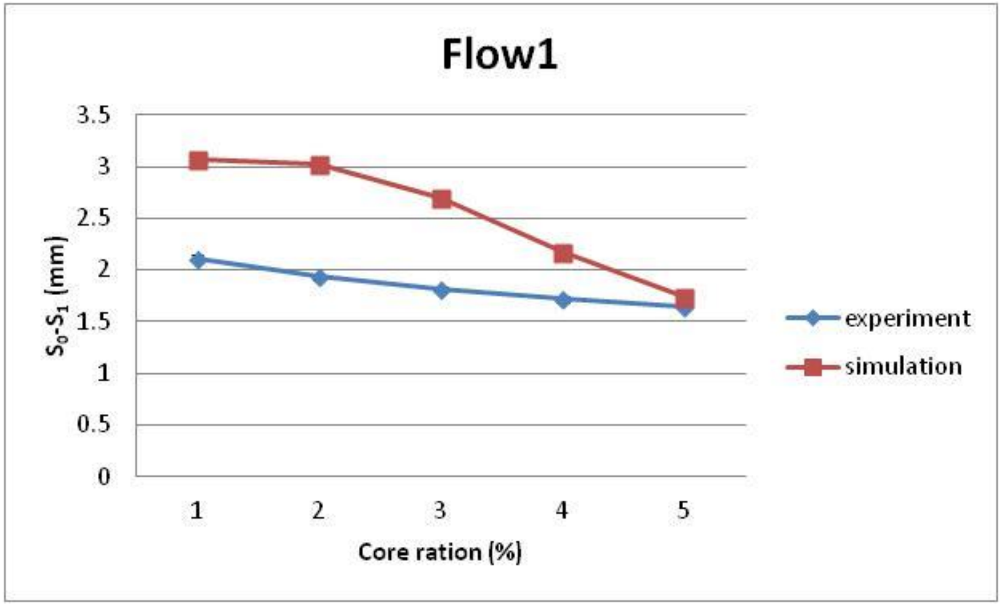


	Shot	Material	Flow rate	Melt temp.
Melt temp. 2	1st	PP	46 cc/sec	230℃
	2nd	PP	46 cc/sec	230℃

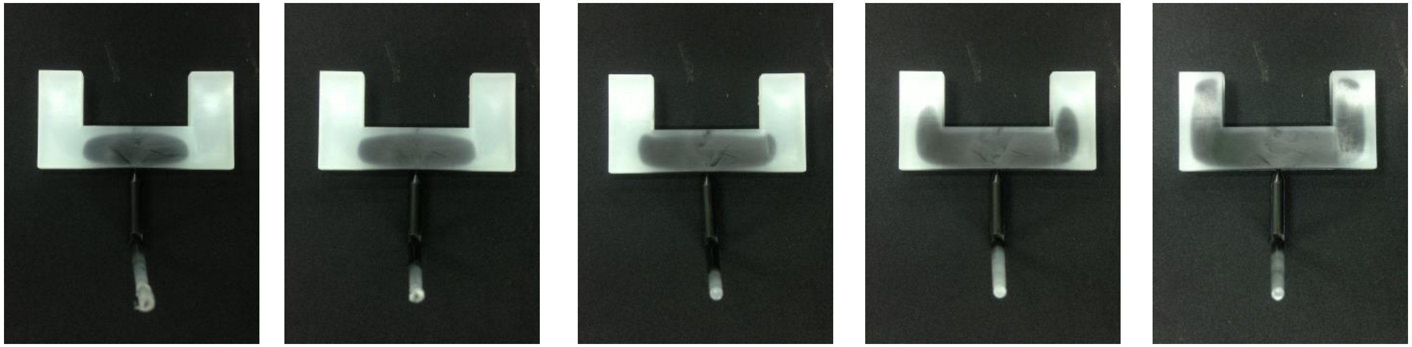


Core ratio(%) 15 20 25 30 40

Flow 1

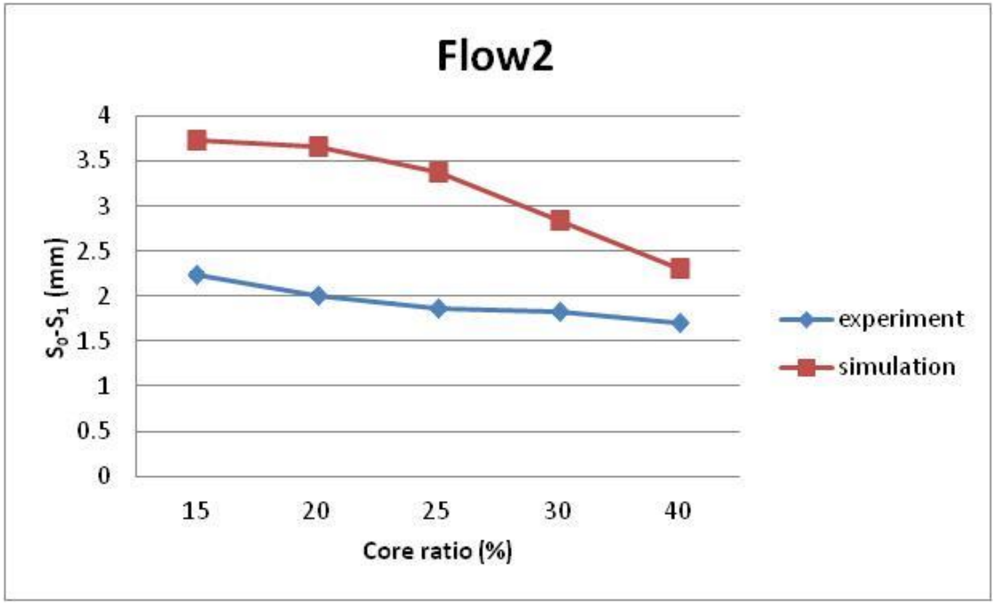


	Shot	Material	Flow rate	Melt temp.
Flow rate	1st	PP	23 cc/sec	190℃
	2nd	PP	46 cc/sec	190℃

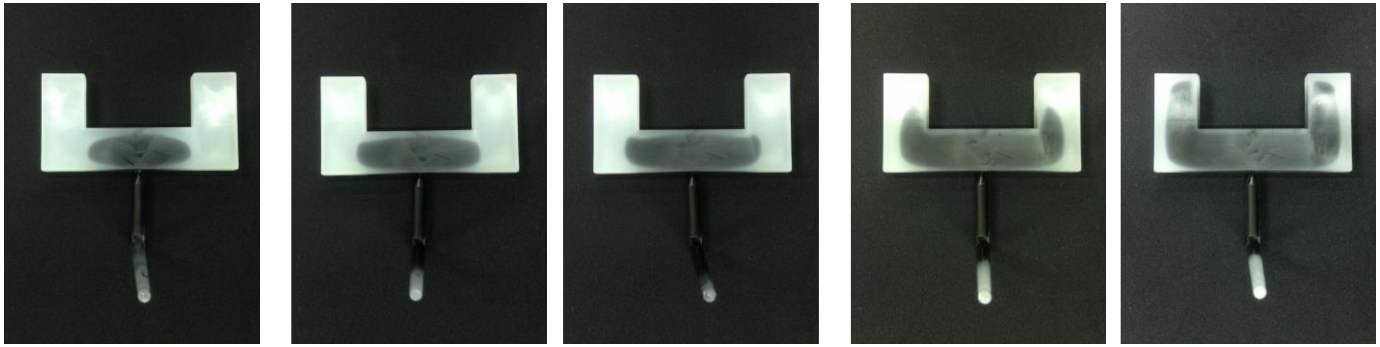


Core ratio(%) 15 20 25 30 40

Flow 2



	Shot	Material	Flow rate	Melt temp.
Flow rate 2	1st	PP	23 cc/sec	190℃
	2nd	PP	23 cc/sec	190℃

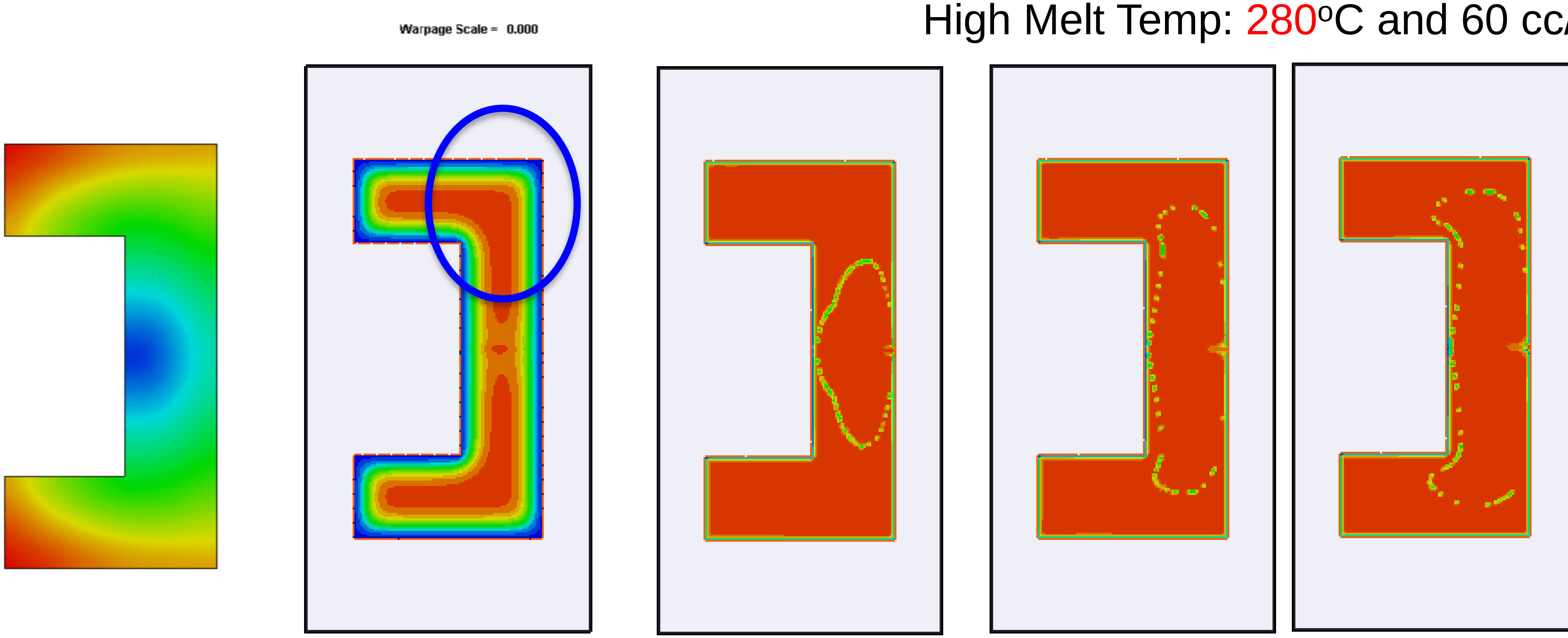


Core ratio(%) 15 20 25 30 40

Discussion

PC/PC Material: ____________

High Melt Temp: 280ºC and 60 cc/sec



Single shot | 10% | 20% | 25%

x3D

:NN3_2R12.mfe/PC_PanliteL-1250Y_1.mtr/MDXProject20140827_1.pro

0.000206 ~ 0.885 Avg: 0.504 mm (Scale:0.00,Total,1.00),Ep=215,036 Ec=0 Em=0 (FastCool) <Mixed>

- **The volume shrinkage result shows that the corner side has larger shrinkageable volume/ accumulated heat due to geometrical design. Thus, during the cooling process, the corner shrinkage tendency is toward inner to cause inner shrinkage warp.**
- **As the second shot passes through the corner region, the discontinuity interface with first shot will compensate the inner shrinkage tendency and improve the Warp results.**

PP Remarks

In this study for warpage mechanism of co-injection

> In PP/PP co-injection (semi-crystalline) system
  - Core ratio effect:
    - The higher core ratio, the better
  - Melt temperature effect:
    - The lower, the better
  - 1st shot effect:
    - The slower 1st shot, the better.

For better prediction of final warpage, the crystallization effects on the volumetric shrinkage of PP should be taken into account in the near future.

Thank you for your attention!